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Revision 0

STP-ECRTS - Thermal and Gas Analyses for Sludge Transport and Storage Container (STSC) Storage at T Plant

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

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STP-ECRTS - Thermal and Gas Analyses for Sludge Transport and Storage Container (STSC) Storage at T Plant

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Total Pages: 305

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

1. Introduction

The Sludge Treatment Project (STP) is responsible for the disposition of sludge contained in the six engineered containers and Settler tank within the 105-K West (KW) Basin. The STP is retrieving and transferring sludge from the Settler tank into engineered container SCS-CON-230. Then, the STP will retrieve and transfer sludge from the six engineered containers in the KW Basin directly into a Sludge Transport and Storage Containers (STSC) contained in a Sludge Transport System (STS) cask. The STSC / STS cask will be transported to T Plant for interim storage of the STSC. The STS cask will be loaded with an empty STSC and returned to the KW Basin for loading of additional sludge for transportation and interim storage at T Plant.

CH2MHILL Plateau Remediation Company (CHPRC) contracted with Fauske & Associates, LLC (FAI) to perform thermal and gas generation analyses for interim storage of STP sludge in the Sludge Transport and Storage Container (STSCs) at T Plant. The sludge types considered are settler sludge and sludge originating from the floor of the KW Basin and stored in containers 210 and 220, which are bounding compositions. The conditions specified by CHPRC for analysis are provided in Section 5. The FAI report (FAI/10-83, *Thermal and Gas Analyses for a Sludge Transport and Storage Container (STSC) at T Plant)* (refer to Attachment 1) documents the analyses. The process considered was passive, interim storage of sludge in various cells at T Plant. The FATE™ code is used for the calculation. The results are shown in terms of the peak sludge temperature and hydrogen concentrations in the STSC and the T Plant cell. In particular, the concerns addressed were the thermal stability of the sludge and the potential for flammable gas mixtures.

This work was performed with preliminary design information and a preliminary software configuration.

2. Background

The STP will retrieve and transfer sludge from the six engineered containers directly into STSCs contained within the STS cask. The STS Cask is designed to stay on the transport trailer. The transport trailer is positioned in the modified annex building at the 105-KWest Basin building. A batch of retrieved sludge is allowed to settle within a STSC to concentrate the solids and clarify the supernatant. After a prescribed solids settling period, the supernatant is decanted and transferred through a sand filter to remove suspended sludge particles. The filtered supernatant is returned to the 105-K West Basin. Subsequent batches of sludge are added to the STSC, settled, and excess supernatant removed in the same manner as previously described until the prescribed quantity of sludge is collected in a STSC. The solids collected on the sand filter are fluidized and flushed directly in the STSC. The STSC and the STS cask are purged with argon gas and configured for transportation to T Plant. At T Plant the STSC is vented / purged, removed from the STS cask and placed in a cell for interim storage.

Three types of sludge will be placed separately in the STSC; 1) K East (KE) Engineered Container sludge, 2) K West (KW) Engineered Container sludge, and 3) Settler Tank sludge. KE Engineered Container sludge originated from vacuuming sludge from the floor of the 105-KE Basin and some fuel canister sludge into engineered containers within the 105-KE Basin. This sludge was then transferred into three engineered containers (SCS-CON-240, -250, -260) within the 105-KW Basin. KW Engineered Container sludge originated from vacuuming sludge from the floor of the 105-KW Basin and some KE and KW fuel canister sludge into two engineered containers (SCS-CON-210 and -220) within the 105-KW Basin. Settler tank sludge is the less than 600-μm fraction of sludge that originated from washing uranium metal fuel in the 105-KW Basin, which is being transferred into engineered container SCS-CON-230. Characteristics of these three sludge types are provided in Tables 1 (from HNF-41051, revision 5 *Preliminary STP Container and Settler Sludge Process System Description and Material Balance*).

For the T Plant storage of STSCs, two sludge types and STSC geometries are considered. Settler sludge is stored in an STSC with an insert so that the sludge is in an annular configuration; KE Engineered Container or KW Engineered Container sludge are stored in an STSC without the insert. The STSC used for Settler tank sludge is designed as an ASME Section VIII pressure vessel with a centrally located inner cylinder. The STSC has 2:1 radius elliptical top and bottom heads. The inner diameter of the STSC is ~1.5 m (58.5 ±0.5-inches). The height of the STSC is ~2.61 m (102.75-inches) from the bottom to the top of the elliptical heads. The outer radius of the cylinder inside the STSC is ~0.3 m (12-inches). The annulus width inside the STSC is ~0.43 m (17-inches). The volume of the annulus is ~2.89 m^3 however the STSC is only filled with 2.7m^3 of sludge slurry and 0.19 m^3 of water used to flush the sludge transfer pipeline. The inner cylinder extends from 2-inches above the bottom of the STSC to the bottom of the top elliptical head. This inner cylinder is sealed at the bottom and opens at the top inside the STSC. The annulus space contains sludge whereas the inner cylinder is filled with water. The water contained inside the inner cylinder provides a heat transfer mechanism for heat generated from radiolytic decay and uranium metal reaction with water.

The volumes of each sludge type are determined based upon transient analyses of on-site transportation (HNF-41051). The STSC used for KE or KW Engineered Container sludge is the same design as the STSC used for Settler tank sludge, except there is no inner cylinder and the STSC capacity is ~3.5m^3. The STSC is filled with 3.31m^3 of sludge slurry and 0.19m^3 of water used to flush the sludge transfer pipeline. Safety-basis sludge properties from HNF-41051 are used in this analysis are given in Table 1.

Table 1 - Properties for Engineered Container and Settler Sludge

Property	KE Originating Containers 240, 250, 260		KW Originating Containers 210 and 220		Settler* Container 230		Units
	Design	Safety	Design	Safety	Design	Safety	
As Settled Density	1.4	1.6	1.6	1.8	2.45	3.25	gm/cm^3
Percent Water in Sludge	75%	75%	74%	74%	70%	70%	Volume %
Total Uranium	0.11	0.38	0.28	0.59	1.34	2.1	g U/cm^3
Uranium Metal Fraction in Settled Sludge - Non-Segregated	0.006	0.030	0.030	0.082	0.052	0.163	g/cm^3
Decay Heat	4.4	26	14	52	54.5	167	W/m^3
Fissile Grams Equivalent (FGE)	7.02E+02	3.48E+03	1.56E+03	7.28E+03	7.34E+03	2.96E+04	FGE/m^3
Sludge Expansion Factors							
Uranium Metal Corrosion	1.02	1.08	1.25	1.35	1.61	1.87	unitless
Gas Retention	1.41	1.54	1.41	1.58	1.41	1.63	unitless
Combined	1.43	1.66	1.76	2.13	2.26	3.04	unitless
*Settler sludge composition is based on 50vol% KE: 50vol%KW Canister Sludge (from HNF-41051, revision 5, *Preliminary STP Container and Settler Sludge Process System Description and Material Balance*)							

During filling of either STSC design, sludge slurry is received into the STSC and is settled by gravity. Excess water is removed by decantation from above the settled sludge and filtered to remove entrained solids. Subsequent batches of sludge are added to the STSC, settled and excess water decanted until the maximum volume of settled sludge in the STSC is obtained. The maximum volume of settled sludge in the STSC is determined from the thermal and gas analyses. Also, the effect of sludge segregation into multiple metal-rich and metal free layers during loading is considered. Stratification of sludge into uranium metal-enriched and metal-free layers may occur during batch sludge loading. Composition of stratified settler sludge is summarized in Table 2 and the composition of the KW Engineered Container sludge is summarized in Table 3.

Passive storage at T Plant may take place in either a standard cell (from the cell number 3R thru 20R) or in a long cell (cell 2R). Six STSCs are placed in a standard cell, and eight STSCs are placed in the long cell. One STSC is modeled in detail for its transient response. The effect of other STSCs that may be present in the cell is approximated by adding heat and hydrogen sources to the cell. See Section 3.0 of the attachment for more details on STSC and T Plant design.

The process cell is assumed to be ventilated at the average low ventilation rate, and the canyon temperature is assumed to be at its highest prescribed value. In alternate scenarios, cell response with loss of ventilation is examined. Overall, scenarios are defined for the various combinations of sludge types and STSC geometries, cell types, and ventilation type. See Section 6.0 of the attachment for a discussion of scenario definitions, and see Section 7.0 of the attachment for a detailed presentation of results.

Table 2 Well-Mixed and Stratified Settler Sludge Properties, Single 0.5 m^3 Batch

Property[1,2,3]	Well-Mixed	Stratified (Layered)	
		Metal Rich	Metal-Free
Density, g/cc	3.250	3.822	2.954
U metal concentration, g/cc	0.1625	0.477	0.0
Total U concentration, g/cc	2.050	2.695	1.716
Water volume fraction	0.70	0.70	0.70
Particle density, g/cc (derived)	8.500	10.409	7.513
Fraction of sludge volume (layer height)	100%	34%	66%
Metal mass fraction	0.06373	0.15274	0.0
Oxide mass fraction	0.84594	0.81195	0.87027
Non-uranium mass fraction	0.09034	0.03531	0.12973

Property(1,2,3)	Well-Mixed	Stratified (Layered)	
		Metal Rich	Metal-Free

(1) Reference: PRC-STP-00162, Plys and Johnson, 2009.
(2) Metal material density is 19.0 g/cc, and per SNF-7765 the oxide material density is 11.1 g/cc with a formula weight of 272. The derived non-uranium material density is 2.372 g/cc.
(3) Density, U metal concentration, Total U concentration, and water volume fraction are fundamental given quantities for defined sludge streams. For well-mixed sludge, volume fractions are derived from these four quantities. The metal-rich and metal-free layer values for the top four quantities given here are derived from the volume fractions listed, which are idealized based upon detailed settling model results.

Table 3 Well-Mixed and Stratified KW Container Sludge Properties, 2 × 0.8 m^3 Batches

Property(1,2,3)	Well-Mixed	Stratified	
		Metal-Rich	Metal-Free
Density, g/cc	1.800	1.8094	1.7937
U metal concentration, g/cc	0.082	0.2050	0.0
Total U concentration, g/cc	0.590	0.5987	0.5842
Water volume fraction	0.74	0.74	0.74
Particle density, g/cc (derived)	4.077	4.1132	4.0527
Fraction of sludge volume (layer height)	100%	40%	60%
Metal mass fraction	0.0774	0.1917	0.0
Oxide mass fraction	0.5811	0.4464	0.6723
Non-uranium mass fraction	0.3415	0.3619	0.3277

(1) Reference: PRC-STP-00220, Plys et al, 2010.

(2) Metal material density is 19.0 g/cc, and per SNF-7765 the oxide material density is 7.5 g/cc with a formula weight of 288.6. The derived non-uranium material density is 2.086 g/cc.

(3) Density, U metal concentration, Total U concentration, and water volume fraction are fundamental given quantities for defined sludge streams. For well-mixed sludge, volume fractions are derived from these four quantities. The metal-rich and metal-free layer values for the top four quantities given here are derived from the volume fractions listed, which are idealized based upon detailed settling model results.

3. Major Assumptions

A complete list of assumptions is given in Section 4.0 of the attachment including the following key assumptions.

Key Fate calculation assumptions are:

The FATE™ sludge model considers pertinent phenomena at an appropriate level of detail (see Section 5 of the attachment). Notable model features include the correlation for the rate of uranium metal oxidation, the shrinking-core model for metal oxidation, local water evaporation into evolved hydrogen gas bubbles, representation of sludge properties consistent with the SNF databook, radiolysis, and mass and energy balances.

Heat sinks have idealized external boundary conditions. In most cases, the "inside" boundary condition is convection to the cell or other region atmosphere, while the "outside" boundary condition is insulated. This is valid for concrete for a time scale of about a day but not for several weeks, but the effect of a variation in external temperature is considered to be second-order with regard to its impact on cell temperature

The STSC and its contents are azimuthally symmetric, so that two-dimensional discretization in the axial and radial dimensions provides a sufficient description for the evolution of composition and temperature within the sludge and STSC structure.

While the temperature distribution in the sludge and STSC structure is distributed, the overlying water pool and gas spaces are well-mixed.

The STSC has two open, unfiltered vents open to the T Plant cell configured to provide a stack height to induce natural circulation. The inlet vent diameter is 2 inches (0.0508 m), and the outlet vent diameter is 4 inches (0.1016 m) with a stack height (elevation difference between the tops of the outlet and inlet) of 2 feet (0.6096 m).

Holes in the support skirt are sufficiently large and numerous to permit effective natural circulation heat transfer from the elliptical bottom head to gas inside the skirt and eventual convective exchange of gases inside and outside the skirt.

Key assumptions regarding sludge properties are:

Sludge is loaded in batches as described in the scenario descriptions. Within each batch, the sludge material is assumed to separate (or segregate) into a lower layer containing all the metallic uranium of the batch, and an upper layer that is metal-free. The composition of each layer is given by a model described in PRC-STP-00162 (Settler sludge) and PRC-STP-00220 (KW Engineered Container sludge).

Safety basis sludge properties define the batch properties.

Key assumptions regarding T Plant modeling are:

One STSC is modeled in detail for transient behavior, while the others are represented by average heat and hydrogen generation rates. The detailed STSC is referred to as the "active STSC". The validity of this assumption depends upon many factors including the arrival time of the previous STSCs, the prevailing cell temperature history, and the values chosen to represent the remaining STSCs.

Four other standard process cells containing STSCs are considered, and average heat sources are used for these cells. Considering these cells leads to a slight (around 10%) reduction in circulation flow through the standard cell modeled in detail. Including these cells has no impact on cases considering cell 2R in detail since cell 2R is ventilated via a separate external earthen ware pipe to the ventilation duct while the standard cells each are directly connected to the ventilation duct.

Worst case cover block gaps are assumed in the process cells and nominally worst case cover block gaps are assumed for the pipe trench, in order to minimize natural circulation flows with no ventilation. With ventilation, the choice of resistances is moot because the cell purge rate is sufficiently high as borne out by results.

Standard cells can have a natural circulation flow pattern involving the pipe trench, ventilation duct (i.e. air tunnel), and canyon, which is independent of the natural circulation flow pattern involving long cells (e.g. cell 2R) connected by the 24" external ventilation pipe.

The effect of the T Plant stack is not considered for cases without ventilation. Diurnal temperature variations in the ambient are considered.

4. FATE™ Description and Validity

The FATE™ computer program is used for this work (SNF-23281, 2004, *Description of the Fauske & Associates FATE 2.0 Computer Model*) (the TM symbol will be dropped for simplicity). Some changes have been made to the baseline sludge model from these references, and they will be documented under Quality Assurance in follow-on work (see Section 5.3 of the attachment). FATE version 2.061 is used for this work.

The FATE sludge model was developed by FAI for the Hanford Spent Nuclear Fuel Program and the K Basins Closure Project under the FAI QA program. FATE has been used for K Basins sludge applications including scoping calculations, normal and off-normal behavior, and accidents including pump station spills and spray leaks at CVD.

Briefly, FATE can model heat transfer, fluid flow, and chemical reactions in sludge, its containers, a cask if present, a building or facility containing them, and the environment. Decay power, oxidation power, and conversion of metal to oxide with decrease of reactive surface area are included. Heat conduction in sludge and its container is allowed in one or more dimensions, according to the problem; natural convection occurs in overlying water or air. Pressure, temperature, gas composition, and exchange flows are considered in control volumes that typically consist of the container headspace and surrounding compartments.

The scope of calculations considered here is within the scope of model testing and previous applications, and does not involve untested model capabilities.

Figure 1 shows the FATE model for the STSC and sludge for the cases of settler sludge. Two-dimensional axisymmetric heat conduction in sludge is modeled using 20 stacks of short disk heat conductors connected vertically for conduction, 10 in the cylindrical part and 10 in the bottom head of STSC. Each heat conductor has 20 radial nodes. Hence, each heat conductor node is approximately 3.7 cm in radial extent and 7.0 cm in height. Attachment A provides the corresponding list of regions, junctions, and heat sinks. Corresponding to each sludge heat conductor layer, the STSC wall is modeled as separate heat conductors. Heat generated in the sludge is conducted radially out to the STSC wall, where it is lost by convection and radiation to the cell atmosphere. Heat is also conducted vertically upward to the sludge top, where it is removed by overlying water. Figure 2 shows the FATE model representation for T Plant.

Figure 1 FATE® Model Representation for the STSC with Settler Sludge.

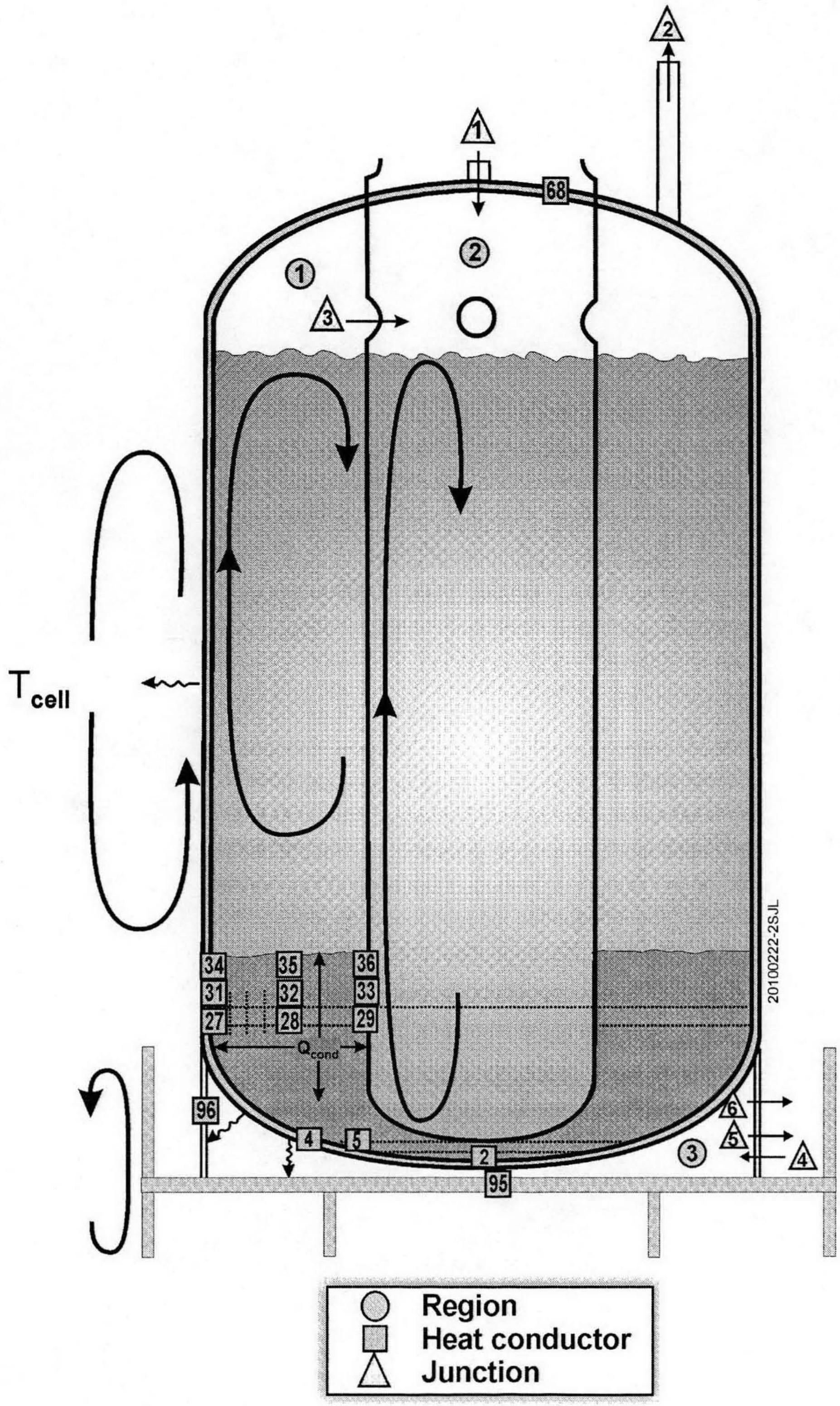
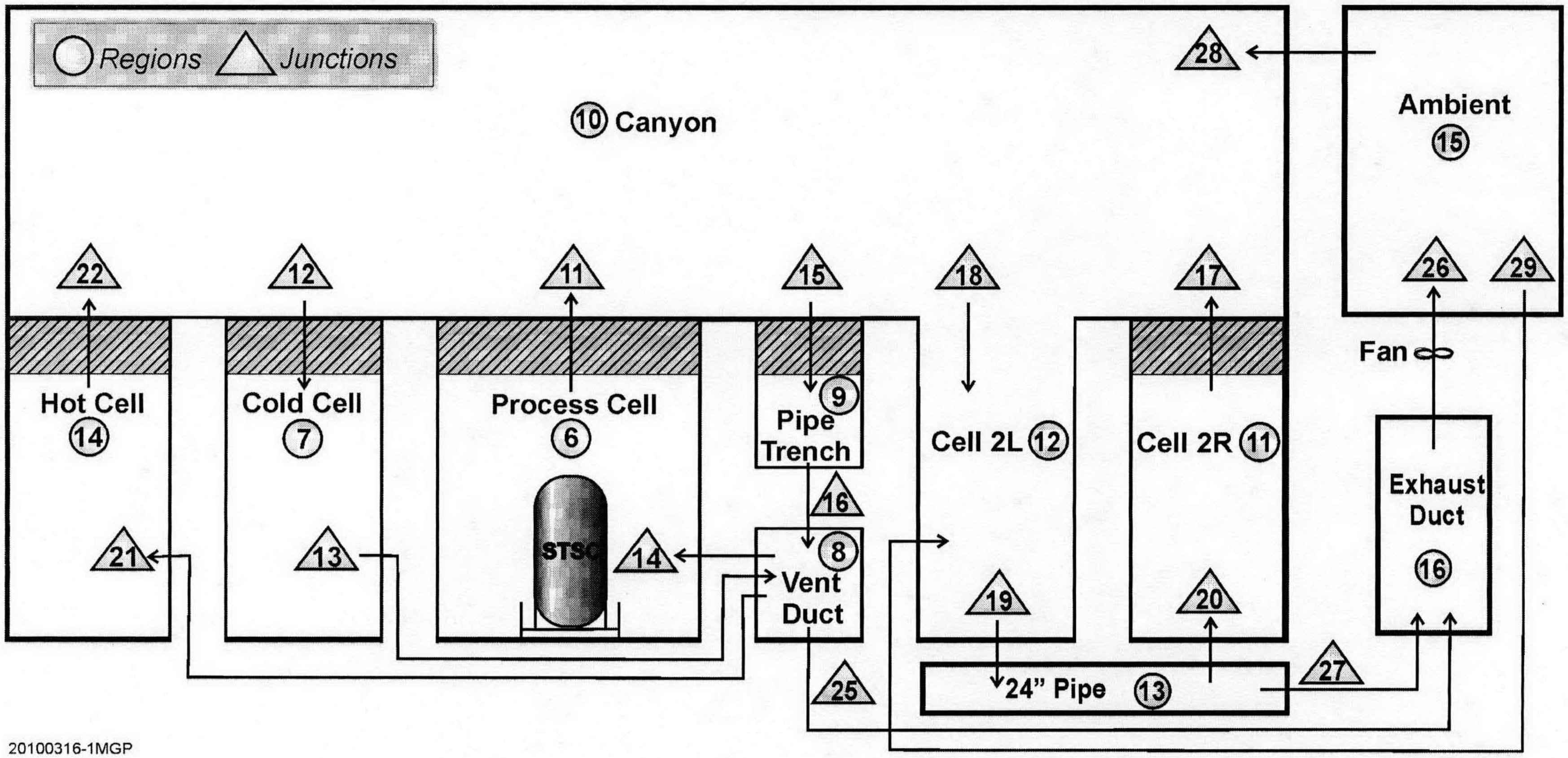


Figure 2 FATE® Model Representation for T Plant.



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5. Conditions for Thermal and Gas Analyses

CHPRC specified eight cases for thermal and gas analysis by FAI, as listed in Table 4. There are three main attributes distinguishing the cases:

Sludge type, volume, and STSC geometry. For settler sludge the volume is always 0.5 m^3 and the STSC geometry includes the insert. For KW container sludge the volume is always 1.6 m^3 and the STSC does not have an insert.

Cell containing the STSC. The STSC is placed in either a standard cell or else in cell long. There are always 6 STSCs in a standard cell and 8 STSCs in a long cell

T Plant Ventilation. Cases with and without T Plant ventilation are considered. With ventilation, the ventilation rate per cell is determined by the relative flow resistances as discussed in Attachment A.

Table 4 Sludge Interim Storage Cases Calculated.

Case	Name and Input Files(1)	Sludge Type	Sludge Volume(2)	STSC Geometry	Ventilation	Cell Type
1a	CONTRF1	KW floor	1.6 m^3	No insert	Yes	Standard
1b	CONTLF1	KW floor	1.6 m^3	No insert	Yes	2R
2a	CONTRN1	KW floor	1.6 m^3	No insert	No	Standard
2b	CONTLN1	KW floor	1.6 m^3	No insert	No	2R
3a	SETTRF1	Settler	0.5 m^3	Insert	Yes	Standard
3b	SETTLF1	Settler	0.5 m^3	Insert	Yes	2R
4a	SETTRN1	Settler	0.5 m^3	Insert	No	Standard
4b	SETTLN1	Settler	0.5 m^3	Insert	No	2R

(1) Each case has two input files, a "case file" and a "base file" The case input file name is the same as the case name. The naming convention for cases and files is as follows:

Case name and case file. The case file defines case-specific boundary conditions including the cell geometry and sludge properties. The naming convention uses letter groupings as follows:

Initial 3 letters: CON for KW floor (containerized), SET for settler sludge,
Letter 4: T for T Plant cell,
Letter 5, Cell type: R = regular, i.e. standard (cells 3 through 20), L = long (cell 2R), and
Letter 6, Ventilation type: F = T Plant fans running, N = no fans.
Letter 7, Version number: 1

Base file. The base file contains defines the STSC geometry and the geometry of heat conductors representing the sludge. The base file for all KW floor sludge cases (1a through 2b) is CON2STSC1.dat. The base file for all settler sludge cases (3a through 4b) is SET1STSC1.dat.

(2) Sludge is stratified into metal-bearing (lower) and metal-free (upper) layers. In all KW floor sludge cases there are 2 pairs of layers corresponding to 2 batch loadings. In the settler sludge case there is one batch and one pair of layers.

6. Discussion of Results

Calculation results are summarized in Table 5.

In all cases the transient duration simulated was 20 days. This duration is sufficient to allow maxima in sludge temperature, hydrogen generation rate, and STSC and cell hydrogen concentrations.

The cell hydrogen concentration is negligible in all cases with normal ventilation; without the ventilation fans, the peak cell hydrogen concentration reached 1.5%. Correspondingly within the STSCs, with ventilation the STSC hydrogen concentration reached 1.6%, and without ventilation it reached 3.3%. In all cases the peak STSC hydrogen concentration was below the lean flammability limit of 4% hydrogen in dry air.

Table 5 Transient Results Summary for KW Floor Sludge Shipping in an STSC.

Case	Thermal Stability	Peak Sludge Temperature [°C]	Peak Power [W]	Peak H_2 Rate [liter/day]	Peak H_2 Concentration in Cell [%]	Peak H_2 Concentration in STSC [%]
1a	Stable	60°C at 16 d	195	830	<0.1	1.6
1b	Stable	58°C at 16 d	190	770	<0.1	1.5
2a	Stable	72°C at 15 d	270	1300	1.0 No ventilation	3.3 No ventilation
2b	Stable	67°C at 16 d	210	1150	1.5 No ventilation	3.1 No ventilation
3a	Stable	53°C at 8d	190	670	<0.1	1.3
3b	Stable	52°C at 8d	190	640	<0.1	1.4
4a	Stable	61°C at 9d	230	960	1.0 No ventilation	2.8 No ventilation
4b	Stable	57°C at 10d	210	830	1.5 No ventilation	3.0 No ventilation

There is no significant impact between the choice of storage in a standard cell (cases designated with a "a") or a long cell (cases designated with a "b"). The present calculations have considered cells fully loaded with the maximum number of STSCs because this will lead to the worst boundary condition for thermal response. In cases without active ventilation the number of STSCs in a cell affects natural circulation, which affects cell and STSC hydrogen concentrations; other scenario definition factors such as the effect of time of year on canyon and cell temperatures can also influence hydrogen concentrations.

Ventilation availability plays the largest role in STSC thermal response. T-Plant ventilation is capable of cooling STSCs and removing hydrogen from the cell atmosphere. Without ventilation, the STSCs heat up more, and natural circulation through cover blocks is required to remove it from the cell.

The character of the sludge - volume, number of batches loaded, and material composition - plays the next most significant role in determining the thermal behavior of an STSC. The single-batch loading of Settler sludge concentrates uranium metal in the lower head of the STSC where heat transfer is the lowest. This is a worst-case scenario since it is likely that it will require more than one batch transfer to load a STSC with Settler sludge. Note that it is not deemed credible to load the KW Engineered Container sludge as a single batch in a STSC. However, KW Engineered Container sludge was modeled as the next worst-case scenario as two batches loaded into a STSC which similarly concentrates the uranium metal in the lower head of the STSC.

Cell size has the least effect on STSC thermal stability. Larger cells have more heat transfer area to the T Plant's thick concrete walls which tends to remove more heat in cases without ventilation. The increased cell volume dilutes hydrogen released from the STSC, leading to a denser atmosphere than the standard cells in no ventilation cases. In the cases with ventilation, the heat load from the additional older STSCs tends to slightly increase the cell and sludge temperature.

The attachment provides the first calculation of the behavior of sludge stored in STSCs at T Plant to employ a detailed building model that considers standard cells in various states, the long cells, and the pipe trench, and allows for natural circulation between the canyon and groups of cells. . The flow split between cells with fans on and the circulation patterns and rates with fans off are affected by assumptions that underlie the flow resistance values input to the model. It should be recognized that cover block gap resistances are based upon old specifications and selected field measurements of gaps at deck level. Actual flow and pressure balance conditions used at T Plant during contemporary operation may differ from what is documented in earlier references.

The circulation patterns and hydrogen concentrations with fans off are also affected by the assumed number of STSCs in a given cell and the number of cells containing STSCs, because these affect cell gas densities via their heat and hydrogen sources. It is also possible that the initial cell conditions, reflecting time of year and the thermal lag between the ambient, canyon, and cells, could influence the flow pattern for fans-off cases. The assumptions built into the T Plant model and fans-off scenarios require further review to ensure that conservative selections have been made.

7. Conclusions

Conclusions of from the discussion of results are:

- Sludge is thermally stable in all cases considered.
- The cell and STSC hydrogen concentrations never exceed 4% for all cases.
- The most important effect on results is ventilation versus no ventilation.
- Results are nearly identical for standard cell and long cell cases; this is the least significant effect.
- The worst cases examined are for KW Engineered Container sludge with no ventilation, cases 2a and 2b, CONTRN1 and CONTLN1. For CONTRN1 the peak hydrogen

concentration is 1.0% in the cell and 3.3% inside the STSC, and the peak sludge temperature is 72°C which occurs at day 15 of the scenario. The cell hydrogen concentration is slightly higher for CONTLN1, about 1.5%.

- T Plant flow conditions, flow resistances, and assumptions for fans-off scenarios should be reviewed to ensure that the contemporaneous configuration is correctly represented and that conservative scenarios have been identified with the updated version of FATE.

8. References

HNF-41051, revision 5, 2009, *Preliminary STP Container and Settler Sludge Process System Description and Material Balance*, CH2MHILL Plateau Remediation Company, Richland, Washington

IINF-SD-SNF-TI-0 15, revision 14A, 2009, Spent Nuclear Fuel Project Technical Databook, Vol. 2, Sludge, CH2MHILL Plateau Remediation Company, Richland, Washington

SNF-23281, 2004, Description of the Fauske & Associates FATE 2.0 Computer Model, Fluor Hanford, Inc., Richland, Washington

STP-PRC-00162, 2009, *Thermal and Gas Analyses for STSC Loaded with Settler Sludge*, CH2MHILL Plateau Remediation Company, Richland, Washington

Attachment

FAI /10-83, Thermal and Gas Analyses for KW Engineered Container Sludge in the STSC / STS Cask

Fauske & Associates, LLC

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& ASSOCIATES, LLC
WORLD LEADER IN NUCLEAR AND CHEMICAL PROCESS SAFETY

Report No.: FAI/10-83

Thermal and Gas Analyses for a Sludge Transport and Storage Container (STSC) at T Plant

Revision 0

Project No.: DESH-12A

Submitted to:

CH2M Hill Plateau Remediation Company
K Basins Closure Project
Richland, Washington

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6	M. Plys	R. Apthorpe
7	R. Apthorpe	S.J. Lee, M. Plys
8	M. Plys	S.J. Lee
App. A	S.J. Lee	R. Apthorpe, M. Plys
App. B	R. Apthorpe	S.J. Lee
App. C	Various – see sections	Not Applicable

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 PURPOSE AND SCOPE

The purpose of this report is to document transient thermal and gas generation analyses for interim storage of KW sludge in the Sludge Transport and Storage Container (STSC) at T Plant. The sludge types considered are settler sludge and sludge originating from the floor of the KW Basin and stored in containers 210 and 220, which are bounding compositions.

The process considered here is passive, interim storage of sludge in various cells at T Plant. The STSC design and T Plant geometry are described in Section 3. The FATE™ code is used for the calculation, as described in Section 5 along with a brief discussion of previous T Plant interim storage calculations using FATE.

The results sought are the peak sludge temperature and hydrogen concentrations in the STSC and the T plant cell. In particular, we are concerned with thermal stability of the sludge and the potential for flammable gas mixtures. A list of key assumptions is given in Section 4. Cases considered and the FATE model representations of the STSC and T Plant are described in Section 6, and results and conclusions are given in Section 7.

This work is performed with preliminary design information and a preliminary software configuration.

2.0 SUMMARY OF RESULTS

This report presents transient calculations of temperatures, gas and heat generation, and gas compositions for passive storage of sludge in STSCs stored at T Plant. Two sludge types and STSC geometries are considered. Settler sludge is stored in an STSC with an insert so that the sludge is in an annular configuration, and KW container sludge is stored in an STSC without the insert. The volumes of each sludge type are determined based upon transient analyses of on-site transportation (Apthorpe, Lee, and Plys, 2010; Plys, Lee, and Apthorpe, 2009).

Safety-basis sludge properties from HNF-41051 are used in this analysis. Also, the effect of sludge segregation into multiple metal-rich and metal free layers during loading is considered. A list of key assumptions is given in Section 4.0.

Passive storage at T Plant may take place in either a standard cell from the cell number range 3 to 20, or in a long cell, cell 2R. Six STSCs are placed in a standard cell, and eight STSCs are placed in the long cell. One STSC is modeled in detail for its transient response. The effect of other STSCs that may be present in the cell is approximated by adding heat and hydrogen sources to the cell. See Section 3.0 for more details on STSC and T Plant design.

The process cell is assumed to be ventilated at the average low ventilation rate, and the canyon temperature is assumed to be at its highest prescribed value. In alternate scenarios, cell response with loss of ventilation is examined. Overall, scenarios are defined for the various combinations of sludge types and STSC geometries, cell types, and ventilation type. See Section 6.0 for a discussion of scenario definitions, and see Section 7.0 for a detailed presentation of results.

All configurations analyzed are thermally stable, with a peak sludge temperature of 72°C in the case of container sludge in a normal cell without ventilation. The remaining cases have peak sludge temperatures between 52°C and 61°C.

The cell hydrogen concentration is negligible in all cases with normal ventilation; without the ventilation fans, the peak cell hydrogen concentration reached 1.5%. Correspondingly within the STSCs, with ventilation the STSC hydrogen concentration reached 1.6%, and without ventilation it reached 3.3%. In all cases the peak STSC hydrogen concentration was below the lean flammability limit of 4% hydrogen in dry air.

There is no significant impact between the choice of storage in a standard cell or a long cell. The present calculations have considered cells fully loaded with the maximum number of STSCs because this will lead to the worst boundary condition for thermal response. In cases without active ventilation the number of STSCs in a cell affects natural circulation, which affects cell and STSC hydrogen concentrations; other scenario definition factors such as the effect of time of year on canyon and cell temperatures can also influence hydrogen concentrations. The impact of such factors has not been completely explored and demonstrated to be conservative.

3.0 REFERENCE STSC, SLUDGE, AND T PLANT DATA

3.1 STSC Design

The design considered is an STSC, shown in Figure 3-1 (Johnson, 2009). Note that the diagram shows a central 24" insert. This insert is present for cases with settler sludge, but it is not present in cases with other container sludge. Figure 3-2 provides a simplified illustration of the STSC without the insert. The STSC body consists of elliptical lower and upper heads and a main cylindrical section. The support skirt welded to the lower head, Figure 3-3, features a series of holes allowing air circulation around the lower head.

3.2 Sludge Properties

KW settler sludge will be retrieved from engineered container 230. Floor sludge is assumed to originate from engineered containers 210 and 220 which contain KW floor sludge. Sludge originating from the KE Basin is stored within the KW Basin in containers 240, 250, and 260. The compositions of the KW floor sludge in containers 210 and 220 and the Settler sludge in container 230 bound the composition of the KE sludge in containers 240, 250, and 260 in terms of uranium metal content and total uranium. Therefore, using the KW sludge and Settler sludge in these analyses results in a conservative (i.e. higher) estimate of the hydrogen concentrations in the STSCs and in T Plant.

Stratification of sludge into uranium metal-enriched and metal-free layers may occur during batch sludge loading. Compositions of stratified settler sludge are summarized in Table 3-1, and compositions of KW floor sludge are summarized in Table 3-2. The basis for the settler sludge stratified layer compositions is given in Appendix A of (Plys and Johnson, 2009), and the basis for the KW floor sludge stratified layer compositions is given in Appendix A of (Plys et al, 2010). Note that there is a subtle difference in the definition of the uranium oxide stoichiometry between the two sludge types, reflecting differences in the extent of hydration of the oxide.

Figure 3-1: STSC – Annular Design.

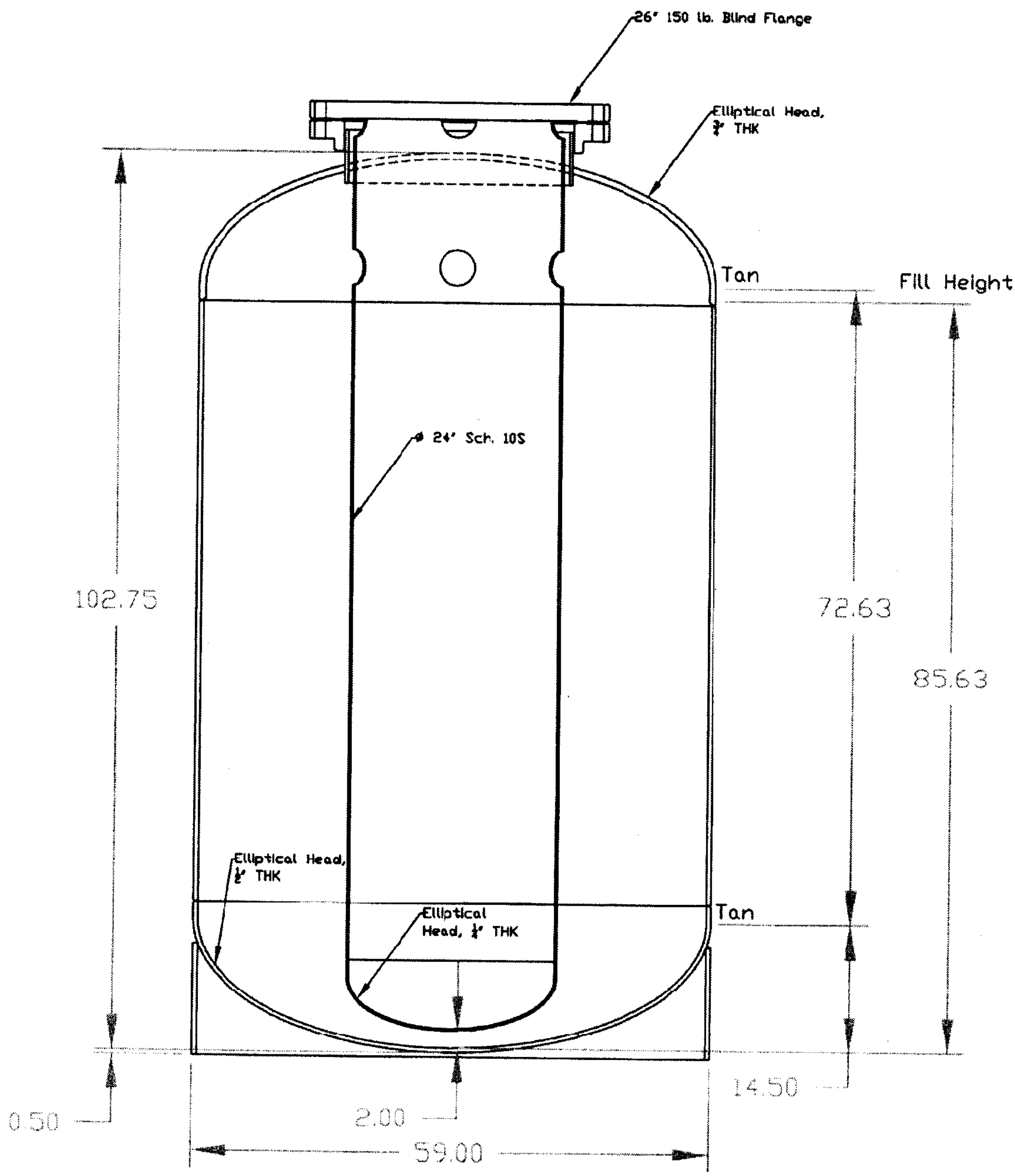


Figure 3-2: Simplified STSC without Insert

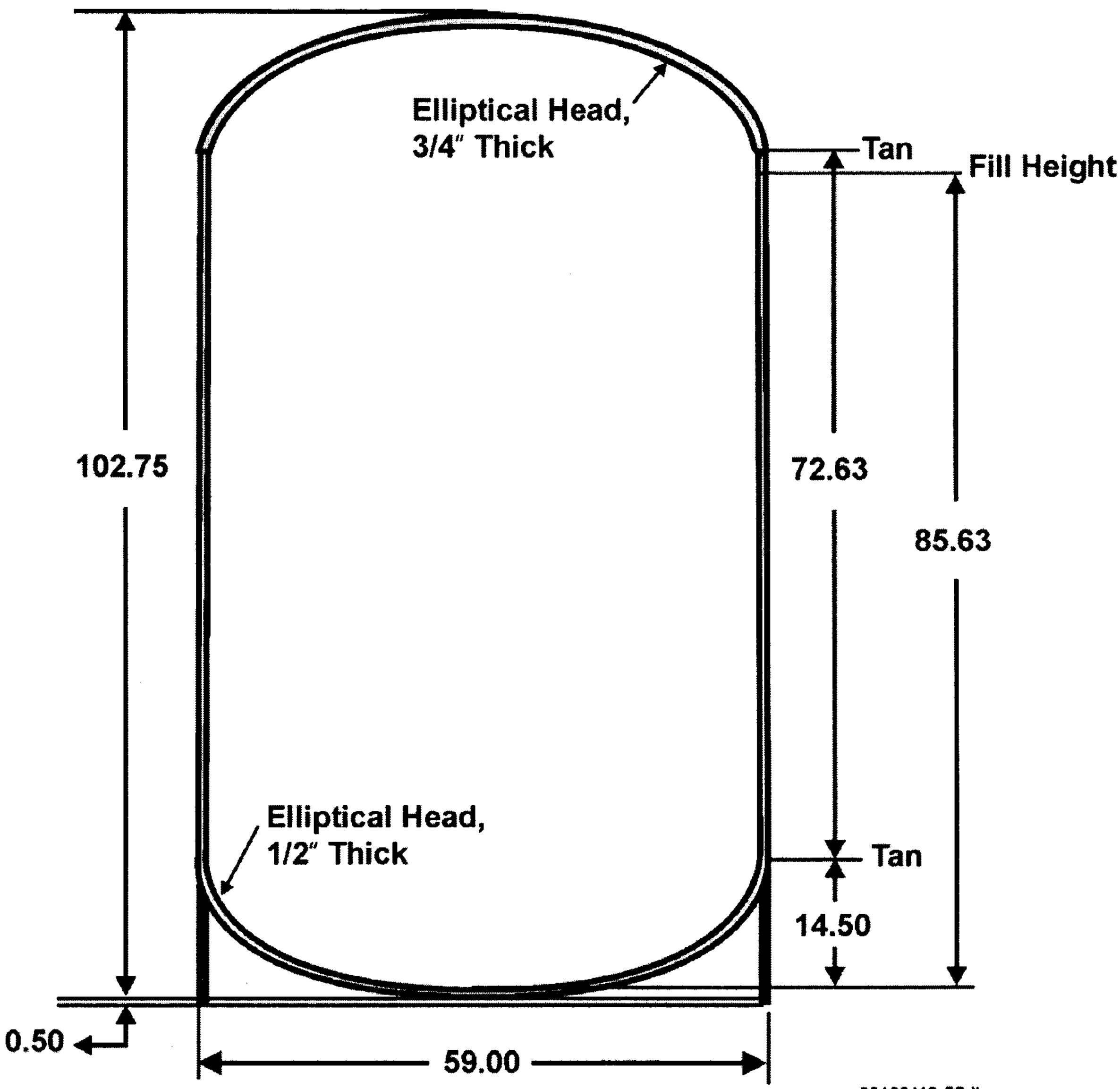
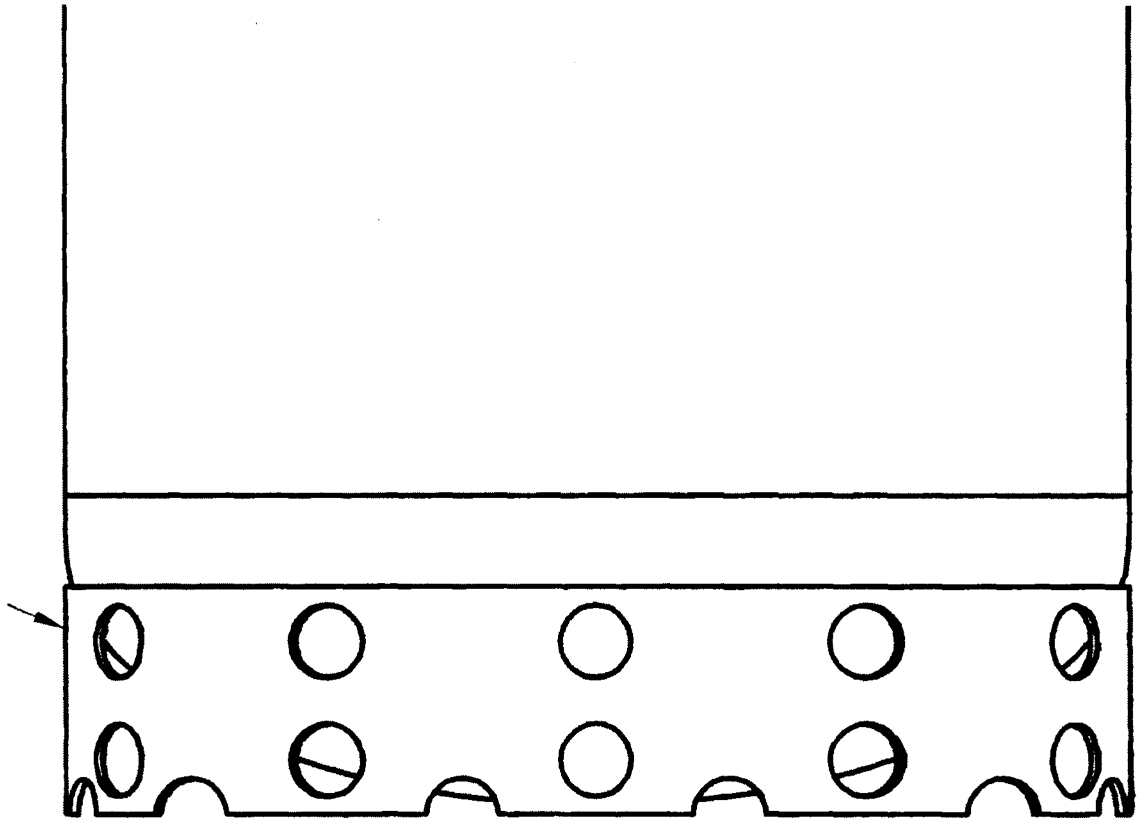


Figure 3-3: STSC Support Skirt.



1 CONTAINER ASSEMBLY

SCALE: 1/10

Table 3-1: Well-Mixed and Stratified Settler Sludge Properties, Single 0.5 m^3 Batch.

Property[1,2,3]	Well-Mixed	Stratified (Layered)	
		Metal-Rich	Metal-Free
Density, g/cc	3.250	3.822	2.954
U metal concentration, g/cc	0.1625	0.477	0.0
Total U concentration, g/cc	2.050	2.695	1.716
Water volume fraction	0.70	0.70	0.70
Particle density, g/cc (derived)	8.500	10.409	7.513
Fraction of sludge volume (layer height)	100%	34%	66%
Metal mass fraction	0.06373	0.15274	0.0
Oxide mass fraction	0.84594	0.81195	0.87027
Non-uranium mass fraction	0.09034	0.03531	0.12973

(1) Reference: PRC-STP-00162, Plys and Johnson, 2009.

(2) Metal material density is 19.0 g/cc, and per SNF-7765 the oxide material density is 11.1 g/cc with a formula weight of 272. The derived non-uranium material density is 2.372 g/cc.

(3) Density, U metal concentration, Total U concentration, and water volume fraction are fundamental given quantities for defined sludge streams. For well-mixed sludge, volume fractions are derived from these four quantities. The metal-rich and metal-free layer values for the top four quantities given here are derived from the volume fractions listed, which are idealized based upon detailed settling model results.

Table 3-2: Well-Mixed and Stratified KW Container Sludge Properties, 2 X 0.8 m^3 Batches

Property[1,2,3]	Well-Mixed	Stratified	
		Metal-Rich	Metal-Free
Density, g/cc	1.800	1.8094	1.7937
U metal concentration, g/cc	0.082	0.2050	0.0
Total U concentration, g/cc	0.590	0.5987	0.5842
Water volume fraction	0.74	0.74	0.74
Particle density, g/cc (derived)	4.077	4.1132	4.0527
Fraction of sludge volume (layer height)	100%	40%	60%
Metal mass fraction	0.0774	0.1917	0.0
Oxide mass fraction	0.5811	0.4464	0.6723
Non-uranium mass fraction	0.3415	0.3619	0.3277

(1) Reference: PRC-STP-00220, Plys et al, 2010.

(2) Metal material density is 19.0 g/cc, and per SNF-7765 the oxide material density is 7.5 g/cc with a formula weight of 288.6. The derived non-uranium material density is 2.086 g/cc.

(3) Density, U metal concentration, Total U concentration, and water volume fraction are fundamental given quantities for defined sludge streams. For well-mixed sludge, volume fractions are derived from these four quantities. The metal-rich and metal-free layer values for the top four quantities given here are derived from the volume fractions listed, which are idealized based upon detailed settling model results.

3.3 T Plant Cell Geometry and Conditions

3.3.1 General Layout

Building 221-T, or simply T Plant, is a large legacy reprocessing facility whose interior has been incompletely remediated from its original mission. T Plant is 850 ft (259 m) long, 74 ft (22.6 m) high, and 68 ft (20.7 m) wide and covers an area of 57,800 ft^2 (5370 m^2). It is made of reinforced concrete. A cutaway view of T Plant in Figure 3-4 shows the relative position of a process cell, the canyon, and various galleries that run past the cells.

A schematic floor plan layout in Figure 3-5 shows a "head end" set of four "long" cells TB, TA, 1L, and 1R, long receiver and holding cells 2L and 2R respectively, and a remaining set of 36 standard process cells numbered 3L, 3R, 4L ...20R. Not shown in the layout, a corrugated steel wall divides the canyon between sections 1 and 2, so that the canyon volume above cells TB, TA, 1L, and 1R is effectively isolated from the main canyon volume.

Cell 2L is the location for STSC arrival and admission to T Plant. Unlike the rest of the cells, it is not covered by cell block covers described below. This cell opens to the receiving tunnel which is indicated in Figure 3-5. Cell 2R is a candidate for storage of STSCs, and it differs only from the remaining cells of higher number by its dimension perpendicular to the T plant axis. The current plan for cell use for STSC storage includes cell 2R and selected standard cells.

3.3.2 Cell Layout

A typical standard cell longitudinal section, meaning in the direction of the T Plant long axis, is shown in Figure 3-6. Each cell width is 20 ft wide overall, of which 13 ft is the actual open cell, and 3.5 ft on either side consists of concrete. A plan view of a standard cell is shown in Figure 3-7. From Figure 3-6 and Figure 3-7, we see that the standard open cell width (length along the T-Plant axis) is 13 ft, and that the standard length (perpendicular to the axis on the plan view) is 17 ft 8 in. Also, the cell is 28 ft deep, but the upper 6 ft are occupied by cover blocks, so the actual interior open depth is 22 ft, and the floor is slightly angled for drainage. To summarize, standard cell dimensions are 13 ft (3.96 m) wide, 17 ft 8 in long (5.38 m), and 22 ft (6.71 m) deep. Cell 2R differs only in its length with respect to the other cells (perpendicular to the axis on the plan view), 27 ft 6 in (8.38 m) as shown in Figure 3-8. Cell 2L is the receiver cell connected to the access tunnel, and it has a slightly lower elevation than 2R, Figure 3-9 .

Thus far, only the ideal, empty cell dimensions have been described. Storage of STSC's requires installation of support assemblies as illustrated in Figure 3-10 through Figure 3-12. The big picture of Figure 3-10 shows the relationship between the storage cell, ventilation duct, pipe trench, and canyon, and other major longitudinal features of T Plant such as the electrical gallery, piping gallery, operations gallery, and crane gallery. Figure 3-11 is a close-up for the cell illustrating the position of the support structure and holding pan for six STSCs. This figure clearly shows the slope of the cell floor and the fact that the STSCs will be held in an array about 4 ft above the cell floor. There is a gap between the holding pan and the cell walls evident in both Figure 3-11 and Figure 3-12. Overall, there will be good natural circulation around the STSC's with or without operation of T Plant fans.

A cross-section through standard cell cover blocks is indicated in Figure 3-11. The cell plan view with STSCs of Figure 3-12 shows an outer dash-dot perimeter describing the cover block labyrinth closure and the centerline locations of individual STSCs. Standard cell cover block and gap geometry are shown in more detail in Figure 3-13. These gaps allow communication between the cell and the canyon with ventilation (from canyon to cell) or without ventilation (possible flow in either or both directions). There are three "type 1" covers and one "type 2" or "key" cover. Cell 2R has two additional type 1 covers. Given the gap geometry, the flow resistance can be determined, and employed with various likely boundary conditions to predict the flow direction and magnitude without fan operation.

3.3.3 Ventilation Duct and Pipe Trench Layout

Along the long axis of T Plant, a ventilation duct and pipe trench pass along the standard cells from sections 3 through 20, Figure 3-10. Every standard cell has a 10" ventilation path to the ventilation duct, and in every section (pair of standard cells) there is a 10" ventilation path from the pipe trench to the ventilation duct. Five of the six long cells have similar ventilation paths to a 24 inch header external to the plant which is connected to the ventilation duct downstream of section 3, see Figure 3-14. The pipe trench is covered by a set of cover blocks similar to those covering the cells but of different thickness (only 4.5 ft) and with alternating labyrinth geometries, Figure 3-15.

The significance of these paths is that normal airflow in T Plant is from the canyon through the cover blocks, into the cells and pipe trench, and thereafter into the ventilation duct, the standard path from least contamination to most contamination. The flow resistances offered by the cell and pipe trench cover blocks govern the flow split between individual cells and the trench, and therefore the normal ventilation rate of a standard cell.

3.3.4 Ventilation System

Ventilation duct air exits T Plant at section 3 through a 4 ft by 7 ft (1.22 m by 2.13 m) concrete duct that runs 145 ft (44.2 m) to a 130 kW electrical heater duct. The air is then pulled through four parallel filter trains each consisting of a pre-filter and two stages of HEPA filters, located above ground, each rated at 10,000 cfm (4.72 m^3/s) and with individual dampers. These four ducts are then combined into a single duct connected to the exhaust fans. The fan system consists of two fans in parallel.

Based on normal fan operation, T Plant canyon conditions are found in Table 4-25 of the SNF Sludge Databook (Schmidt, 2009), reproduced here as Table 3-3. The canyon pressure is maintained between -0.15 and -0.50 inches water gage per (Loscoe, 2003). Current canyon pressure and flow conditions may differ from those indicated by these references. Cell conditions depend upon canyon conditions, ventilation flow, and local heat sources.

It is important to recognize that the T Plant ventilation system has functioned almost continuously throughout plant life, and that system downtime is nearly always related to plant maintenance, rather than inadvertent outage. For this work, in order to avoid the invocation of special controls, analyses are conducted with normal ventilation and without normal ventilation.

Without fan operation, the flow between the process cell and the canyon via gaps in the cover blocks could proceed one-way from canyon to cell (normal direction) or from cell to canyon (reverse direction), or as a counter-current exchange flow in both directions. The actual flow pattern depends upon the net effect of global and local stack effects. The global stack effect will tend to draw canyon air into the ventilation duct, through the filters, and up the stack, promoting the normal flow direction. A local stack effect can exist for a process cell whose air density is lower than that of neighbor cells and the canyon, due to either local heating or sources of steam and hydrogen. In this case, air would be drawn from the ventilation duct, into the cell, and upward into the canyon; other process cells would have the normal flow direction and feed the ventilation duct. Finally, a cell with low gas density compared to that of the canyon could also have counter-current exchange flow through the gaps when the local stack effect is weak. In this case, higher density canyon air would flow downward at some gap locations, and lower density cell air would flow upward at the other locations.

Table 3-3: T Plant Operating Conditions [Schmidt, 2009]

Parameter	Minimum	Maximum
Airflow through canyon	17,500 cfm	35,800 cfm
Canyon Temperature	-7 °C	32 °C

Figure 3-4: T Plant Cutaway

T Plant Cutaway

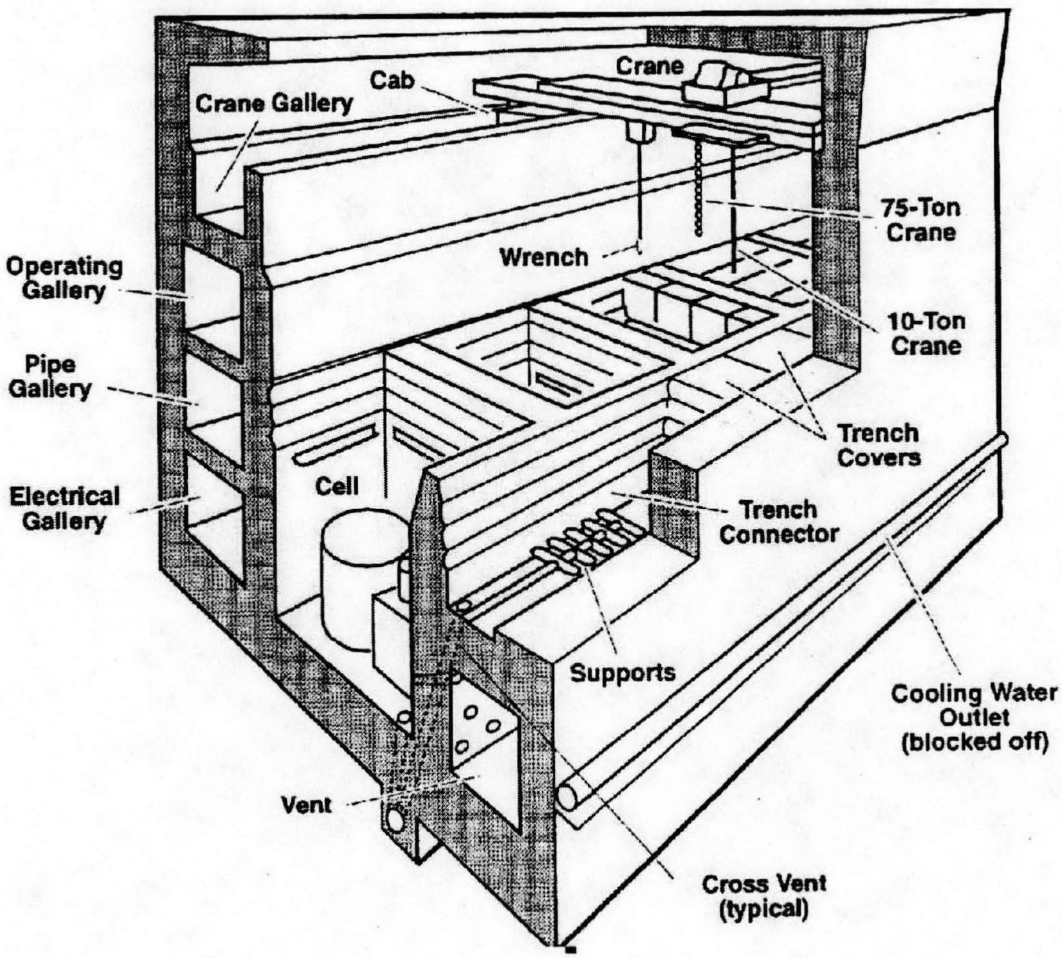


Figure 3-5: T Plant Layout

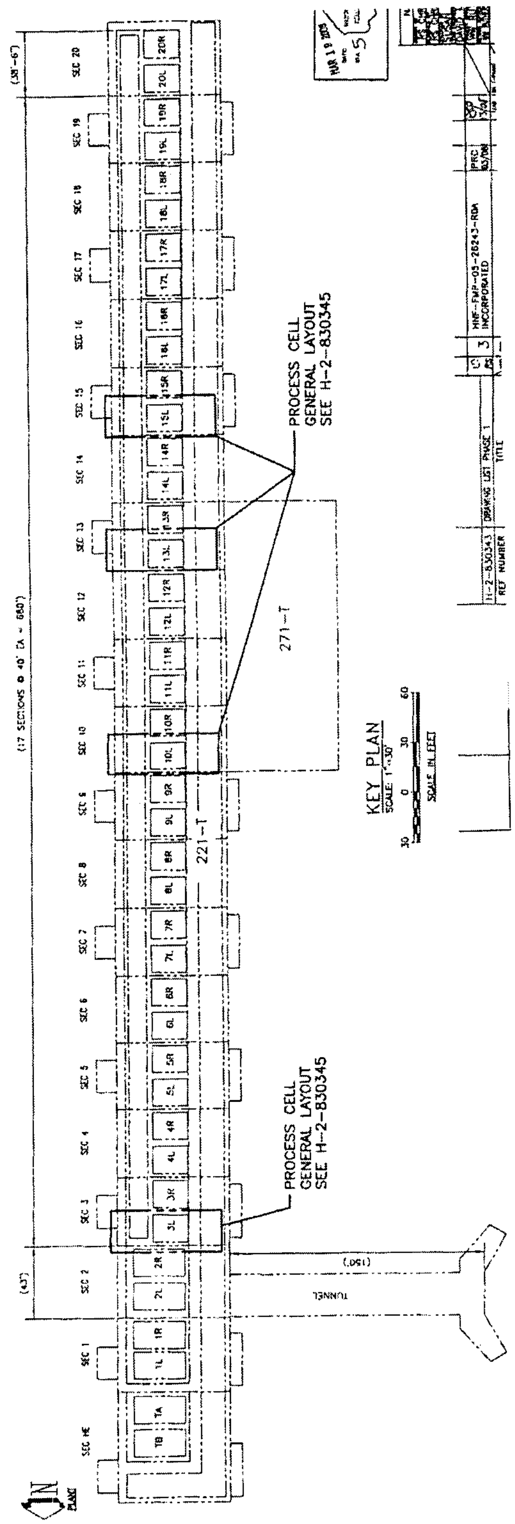


Figure 3-6: Typical Cell Longitudinal Section

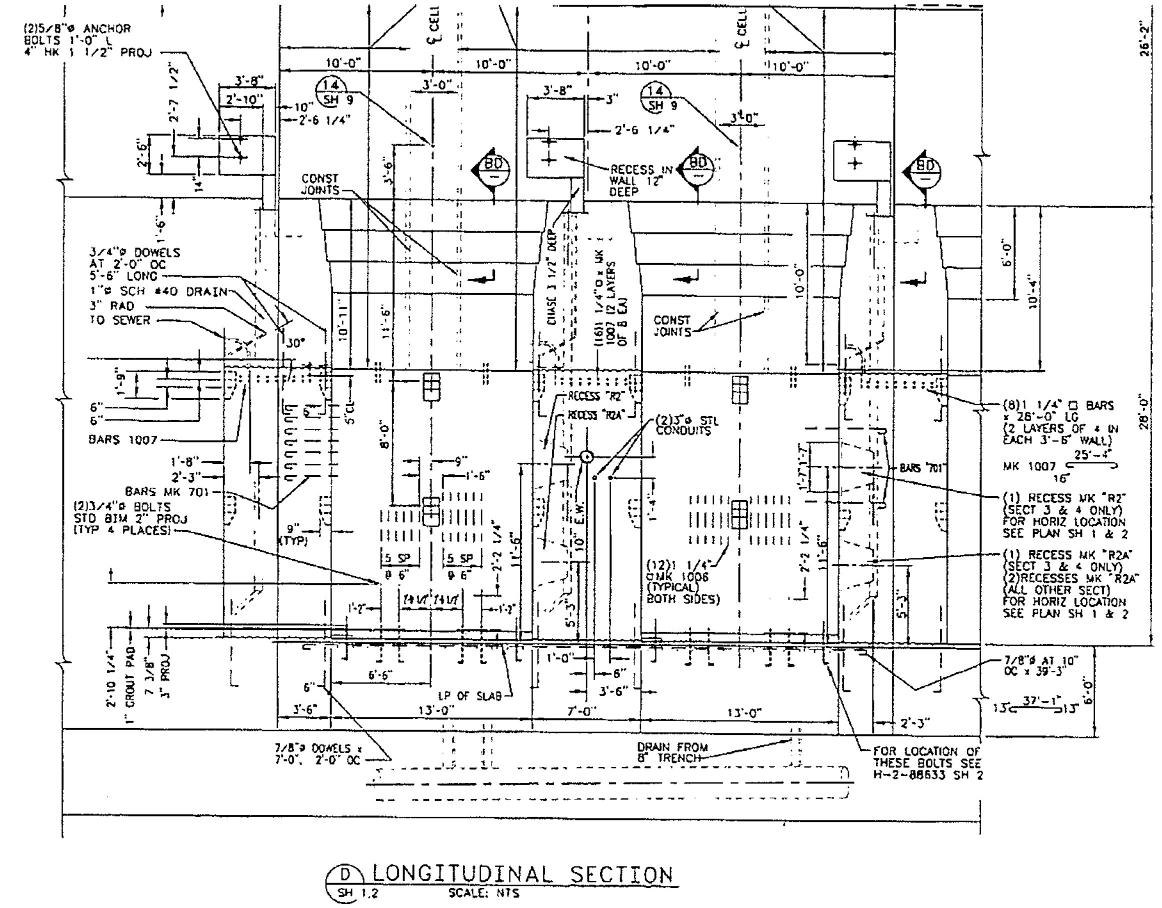


Figure 3-7: Typical Cell Partial Plan

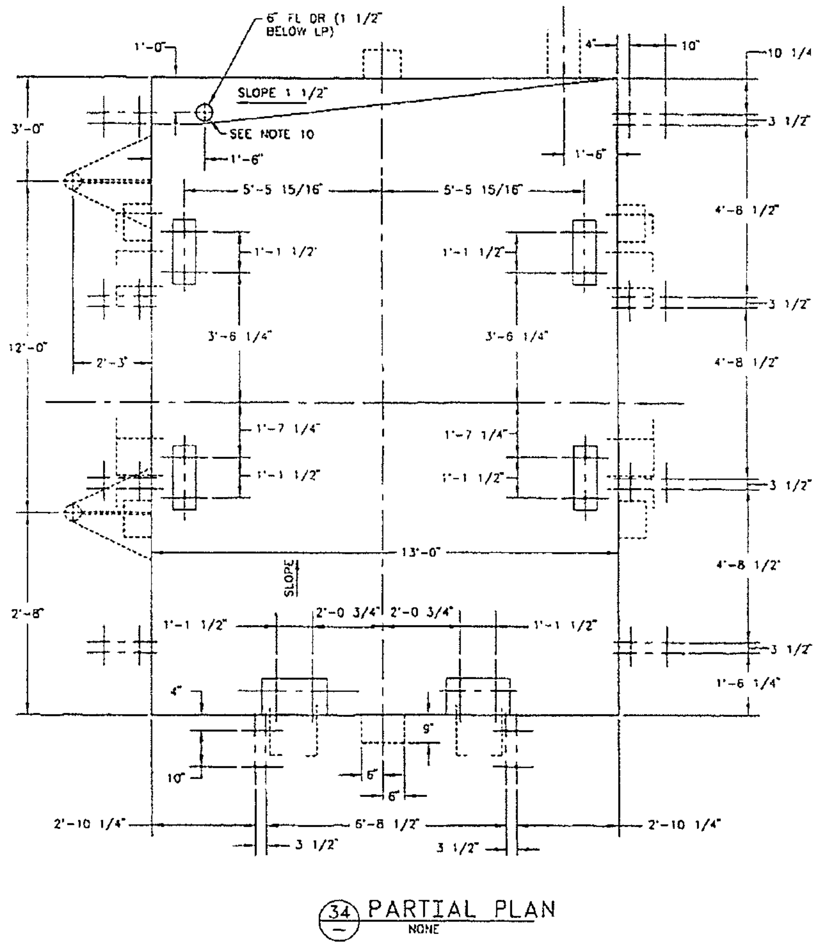


Figure 3-8: Cell 2R Elevation Cross-Section

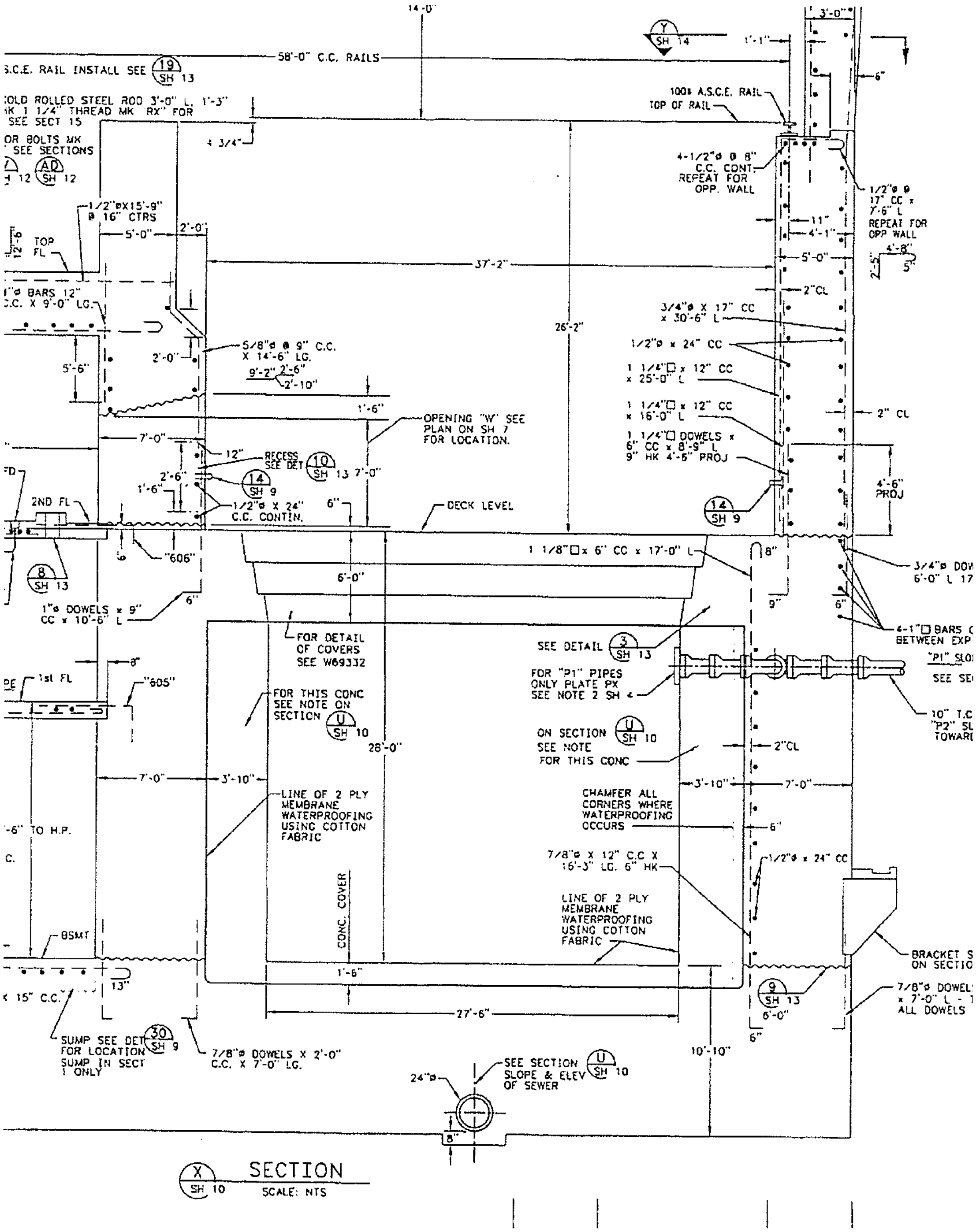


Figure 3-9: Cell 2L (left) and 2R (right) Longitudinal Section

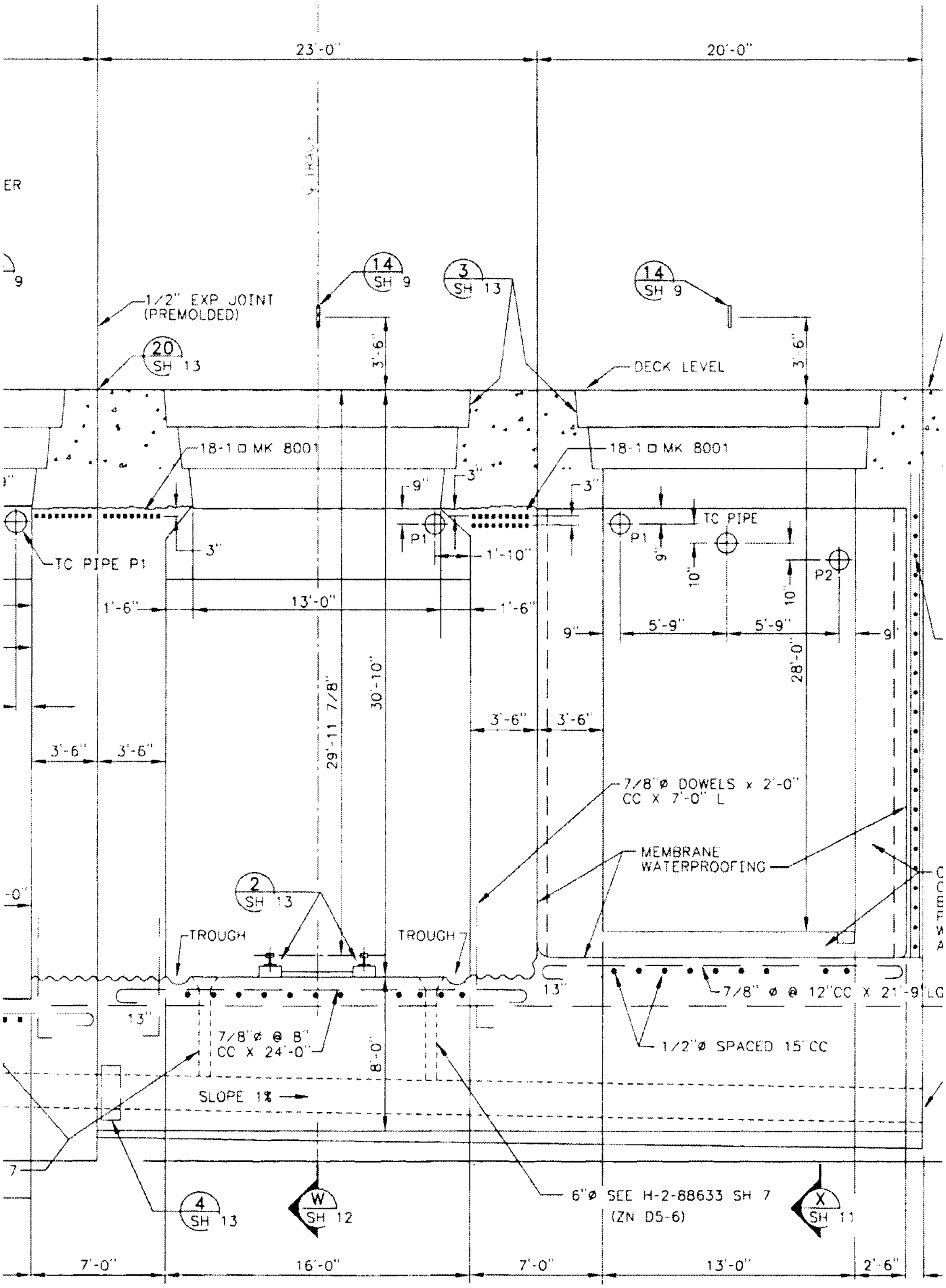


Figure 3-10: T Plant Cross-Section with STSC Receiving Equipment

Figure 3-11: T Plant Detail Cross-Section with STSC Equipment

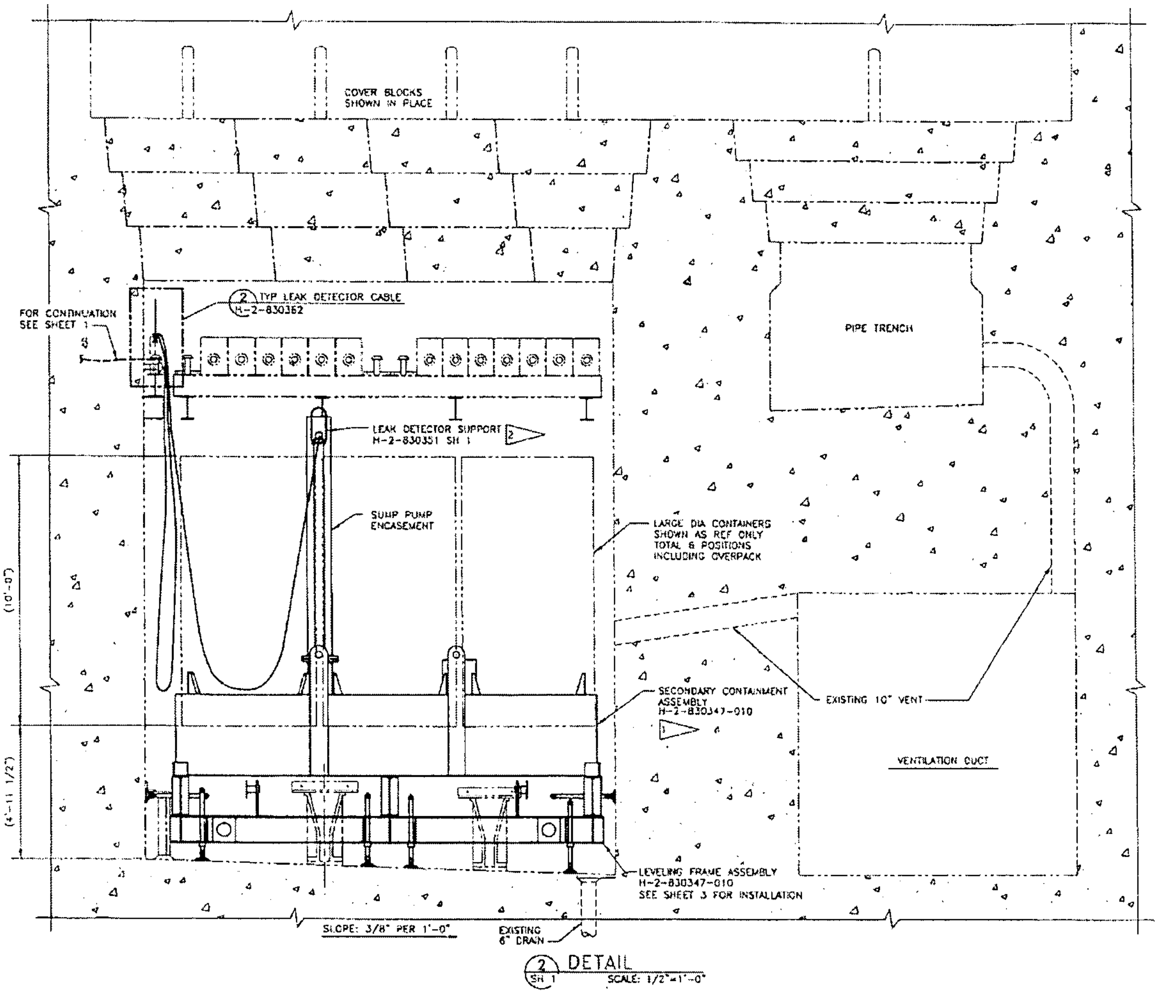
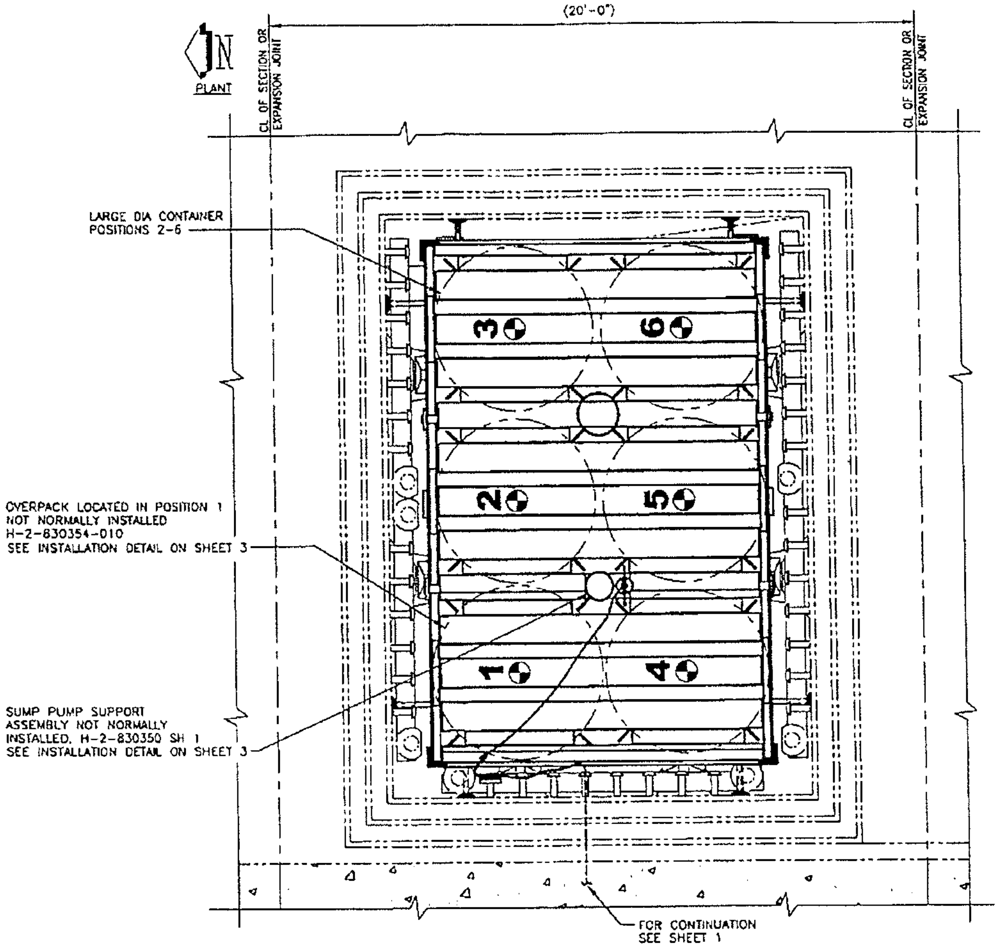


Figure 3-12: Typical Cell Plan with STSC Equipment



1 DETAIL SH 1 SCALE: 1/2"=1'-0"

FLAG NOTES:

1. THE SECONDARY CONTAINMENT ASSEMBLY SHALL BE SET USING THE SECONDARY CONTAINMENT LIFTING DEVICE ON H-2-830349 SH 1. INSTALL TO SIT FLAT ON THE LEVELING FRAME USING THE GUIDES FOR ASSISTANCE.
2. INSTALL THE LEAK DETECTOR INTO THE SECONDARY CONTAINMENT PRIOR TO CONTAINMENT INSTALLATION. KEEP THE PLUG END OF THE ELECTRICAL CORD ON DECK DURING THE INSTALLATION VIA A GUIDE LINE TO ENSURE IT DOESN'T FALL INTO THE CELL.

Figure 3-13: Standard Cell Block Elevation View with Typical Labyrinth Gaps

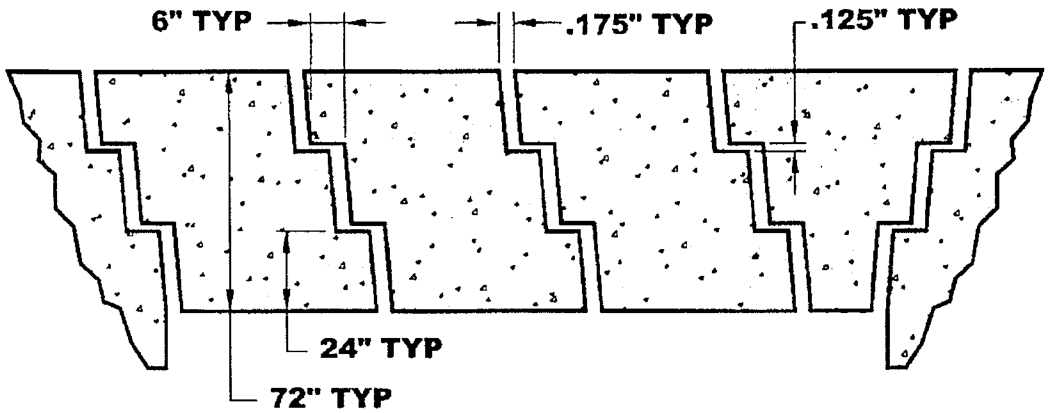


Figure 3-14: 24" Vent Pipe and Connection to Ventilation Duct

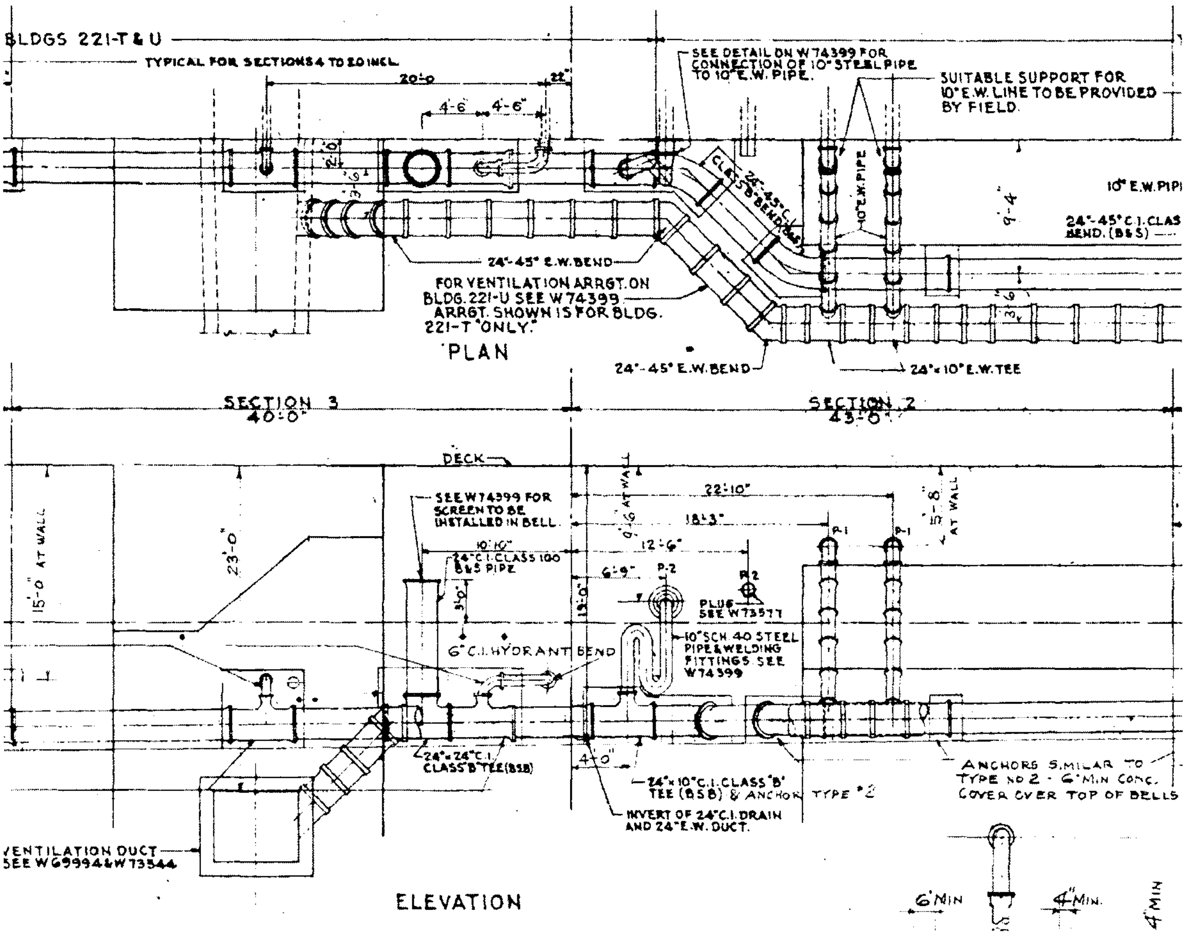
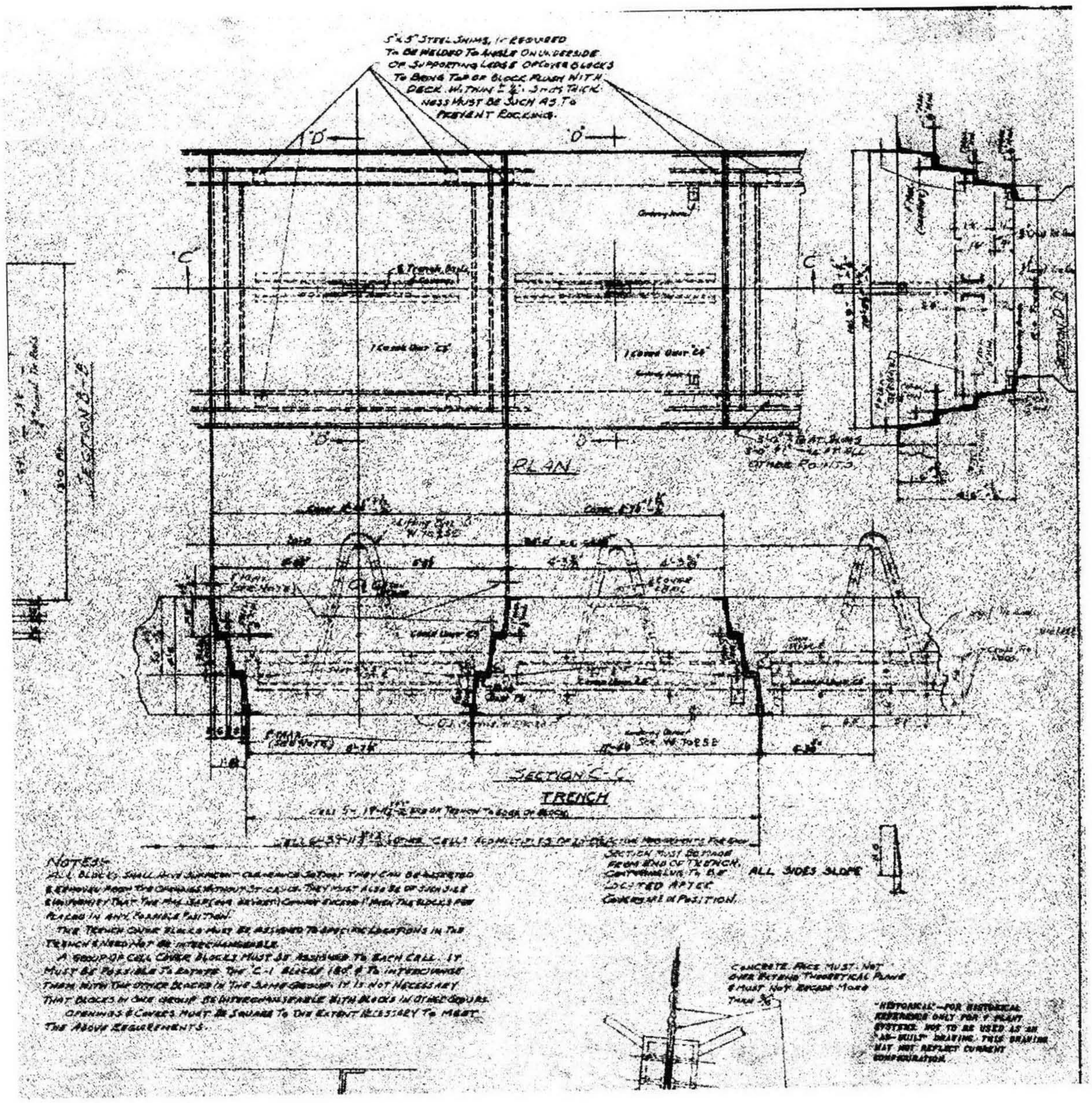


Figure 3-15: Pipe Trench Cover Block Plan and Elevation Views.



4.0 ASSUMPTIONS

4.1 STSC and Sludge Model Assumptions

Key assumptions regarding STSC modeling are:

1. The FATE™ sludge model considers pertinent phenomena at an appropriate level of detail (see Section 5). Notable model features include the correlation for the rate of uranium metal oxidation, the shrinking-core model for metal oxidation, local water evaporation into evolved hydrogen gas bubbles, representation of sludge properties consistent with the SNF databook, radiolysis, and mass and energy balances. The oxygen poisoning model is not employed for radiolysis in this work because of uncertainties in its many input parameters.

2. The STSC and its contents are azimuthally symmetric, so that two-dimensional discretization in the axial and radial dimensions provides a sufficient description for the evolution of composition and temperature within the sludge and STSC structure.

3. While the temperature distribution in the sludge and STSC structure is distributed, the overlying water pool and gas spaces are well-mixed.

4. Holes in the support skirt are sufficiently large and numerous to permit effective natural circulation heat transfer from the elliptical bottom head to gas inside the skirt and eventual convective exchange of gases inside and outside the skirt.

5. The STSC has two open, unfiltered vents open to the T plant cell configured to provide a stack height to induce natural circulation. The inlet vent diameter is 2 inches (0.0508 m), and the outlet vent diameter is 4 inches (0.1016 m) with a stack height (elevation difference between the tops of the outlet and inlet) of 2 feet (0.6096 m).

4.2 Sludge Property Assumptions

Key assumptions regarding sludge properties are:

1. Sludge is loaded in batches as described in the scenario descriptions. Within each batch, the sludge material is assumed to separate (or segregate) into a lower layer containing all the metallic uranium of the batch, and an upper layer that is metal-free. The composition of each layer is given by a model described in (Plys and Johnson, 2009). It is assumed that this model is applicable to the current loading plan.

2. Safety basis properties define the batch properties.

3. The fractions of decay power from alpha, beta, and gamma radiation are based upon isotopic compositions and an externally-supplied spreadsheet calculation described in Appendix A. This spreadsheet will be verified by FAI and described in a future revision of this work.

4. The radiolysis model of SNF-22059 applies (see Appendix A). SNF-22059 provides a calculation of the fraction of alpha, beta, and gamma power that is absorbed by interstitial water, and therefore leads to radiolysis of water. This calculation was performed for several sludge types of interest at the time. A best match to those sludge types is found for sludge compositions used for this work, as identified in Appendix A, so that the power fraction absorbed by water for those reference compositions is used for the sludge compositions in this work. In a future revision of this work, the SNF-22059 calculation methodology will be applied to the sludge compositions considered.

4.3 T Plant Model Assumptions

Key assumptions regarding T plant modeling are:

1. One STSC is modeled in detail for transient behavior, while the others are represented by average heat and hydrogen generation rates. The detailed STSC is referred to as the "active STSC". The validity of this assumption depends upon many factors including the arrival time of the previous STSCs, the prevailing cell temperature history, and the values chosen to represent the remaining STSCs. See Appendix A for the assumed heat and hydrogen generation rates.

2. Four other standard process cells containing STSCs are considered, and average heat sources are used for these cells. Considering these cells leads to a slight (around 10%) reduction in circulation flow through the standard cell modeled in detail. Including these cells has no impact on cases considering cell 2R in detail.

3. Worst case cover block gaps are assumed in the process cell with the active STSC.

4. Worst case cover block gaps are assumed for the remainder of T Plant cells, and nominally worst case cover block gaps are assumed for the pipe trench, in order to minimize natural circulation flows with no ventilation. With ventilation, the choice of resistances is moot because the cell purge rate is sufficiently high as borne out by results.

5. Standard cells can have a natural circulation flow pattern involving the pipe trench, ventilation duct, and canyon, which is independent of the natural circulation flow pattern involving long cells connected by the 24" external ventilation pipe. This is true because the 24" pipe connects to the ventilation system downstream of the ventilation duct serving sections 3 through 20. The nodalization does in fact implicitly allow for any deviation from this assumption.

6. Heat sinks have idealized external boundary conditions. In most cases, the "inside" boundary condition is convection to the cell or other region atmosphere, while the "outside" boundary condition is insulated. This is valid for concrete for a time scale of about a day but not for several weeks, but the effect of a variation in external temperature is considered to be second-order with regard to its impact on cell temperature.

7. For cases with ventilation, the minimum ventilation flow of 17,500 cfm from (Schmidt, 2009) is used, and the minimum canyon pressure of -0.15 inches water gage from (Loscoe, 2003) is used to calculate an effective resistance to air infiltration. The infiltration is assumed to be equally divided between inlet to cell 2L (via the roll-up door) and paths direct to the canyon (such as the rear stairwell doors).

8. The effect of the T Plant stack is not considered for cases without ventilation.

9. Diurnal temperature variations in the ambient are considered.

5.0 FATE™ CODE DESCRIPTION, VALIDITY, AND APPLICATIONS

5.1 FATE™ Description and Validity

The FATE™ computer program is used for this work (Plys and Lee, 2004, Lee and Plys, 2006) (the ™ symbol will be dropped for simplicity). Some changes have been made to the baseline sludge model from these references, and they will be documented under Quality Assurance in follow-on work (see Section 5.3). FATE version 2.061 is used for this work.

The FATE sludge model was developed by FAI for the Hanford Spent Nuclear Fuel Program and the K Basins Closure Project under the FAI QA program. FATE has been used for K Basins sludge applications including scoping calculations, normal and off-normal behavior, and accidents including pump station spills and spray leaks at CVD. A summary of pertinent investigations is given in Table 5-1. The most recent reference applications are for transportation of settler and KW container sludge in an STSC (Plys and Johnson, 2009, and Plys et al, 2010). Conceptual design calculations are found in (Lee and Conzen, 2009). Example calculations similar to those presented here were performed for the earlier LDC design (Plys et al, 2003 and Loscoe, 2003). Applications for sludge retrieval are given in (Plys, 2008), (Plys et al, 2008), and (Plys, Lee, and Epstein, 2009). Applications for sludge processing at elevated temperature are given in (Plys et al, 2006) and (Plys and Lee, 2006).

Briefly, FATE can model heat transfer, fluid flow, and chemical reactions in sludge, its containers, a cask if present, a building or facility containing them, and the environment. Decay power, oxidation power, and conversion of metal to oxide with decrease of reactive surface area are included. Heat conduction in sludge and its container is allowed in one or more dimensions, according to the problem; natural convection occurs in overlying water or air. Pressure, temperature, gas composition, and exchange flows are considered in control volumes that typically consist of the container headspace and surrounding compartments. Aerosol phenomena, combustion, and source terms evaluation can also be treated, but are not used in these calculations; see (Plys, 2007) and (Loscoe, 2003).

The scope of calculations considered here is within the scope of model testing and previous applications, and does not involve untested model capabilities.

Table 5-1: Summary of Pertinent FATE Reference Calculations

Reference	Application
Plys et al, PRC-STP-00220	Transportation of KW floor sludge in an STSC (no annulus). Considers stratification, various loadings, and two levels of insolation.
Plys and Johnson, PRC-STP-00162	Transportation of settler sludge in an STSC, annular design. Considers stratification, various loadings, and two levels of insolation.
Lee and Conzen, 2009 FAI/09-264	Transportation and storage calculations for conceptual designs.
Plys, Lee, and Apthorpe, 2009 FAI/09-065	Sludge process design guidance. Transportation and storage calculations for conceptual designs.
Plys, Lee, and Epstein, 2009 FAI/08-30, R.1	Thermal and gas behavior of containerized settler sludge.
Plys, et al, 2008 FAI/08-32	Thermal and gas behavior of containerized sludge.
Plys, 2008 FAI/08-56	Thermal and gas behavior for retrieval of KOP sludge.
Plys and Lee, 2006 FAI/06-44	High temperature sludge treatment corrosion process, normal operation.
Plys et al, 2006 FAI/06-35	High temperature sludge treatment corrosion process, accident evaluation.
Loscoe, 2003 HNF-12563	Accident scenarios at T Plant including hydrogen combustion during receipt and storage
Plys, Lee, and Malinovic, 2002 FAI/02-13	User's manual for sludge models including example LDC transportation and T plant storage calculations.
Plys and Lee, 2002 FAI/02-11	First LDC transportation and storage calculations.

5.2 Previous T Plant Calculations

The first calculations for T Plant were prepared for the HANSF Sludge manual (Plys, Lee, and Malinovic, 2002). In this document, the method for treating flow through gaps between the cover blocks is discussed in detail. The calculation geometry is similar to the geometry used here, namely, a single cell is in communication with the canyon via the cover block gaps.

A more detailed T Plant nodalization was prepared by (Loscoe, 2003), reproduced here as Figure 5-1. This nodalization was specifically selected in order to invoke FATE source term and aerosol models to predict leak path factors, which is the ultimate goal of FATE application to Hanford process safety analyses to replace dependence upon questionable handbook look-up values. As in any nodalization diagram, be aware that these are high-level representations; for example, the actual flow directions calculated by the model may be opposite those shown by the arrow heads.

Sludge was contained in a container known as the LDC at the time, and LDC dimensions and possible sludge loadings were similar to those of the STSC. Scenarios examined in this report were LDC overpressurization during receipt at T Plant, rapid LDC depressurization during venting upon receipt, hydrogen combustion in an LDC during receipt, LDC exposure to fire in the railroad tunnel, LDC overpressurization in a process cell, and hydrogen combustion in an LDC during water addition in a process cell. Note that the aerosol source term models were used to calculate release fractions and the transport of contamination.

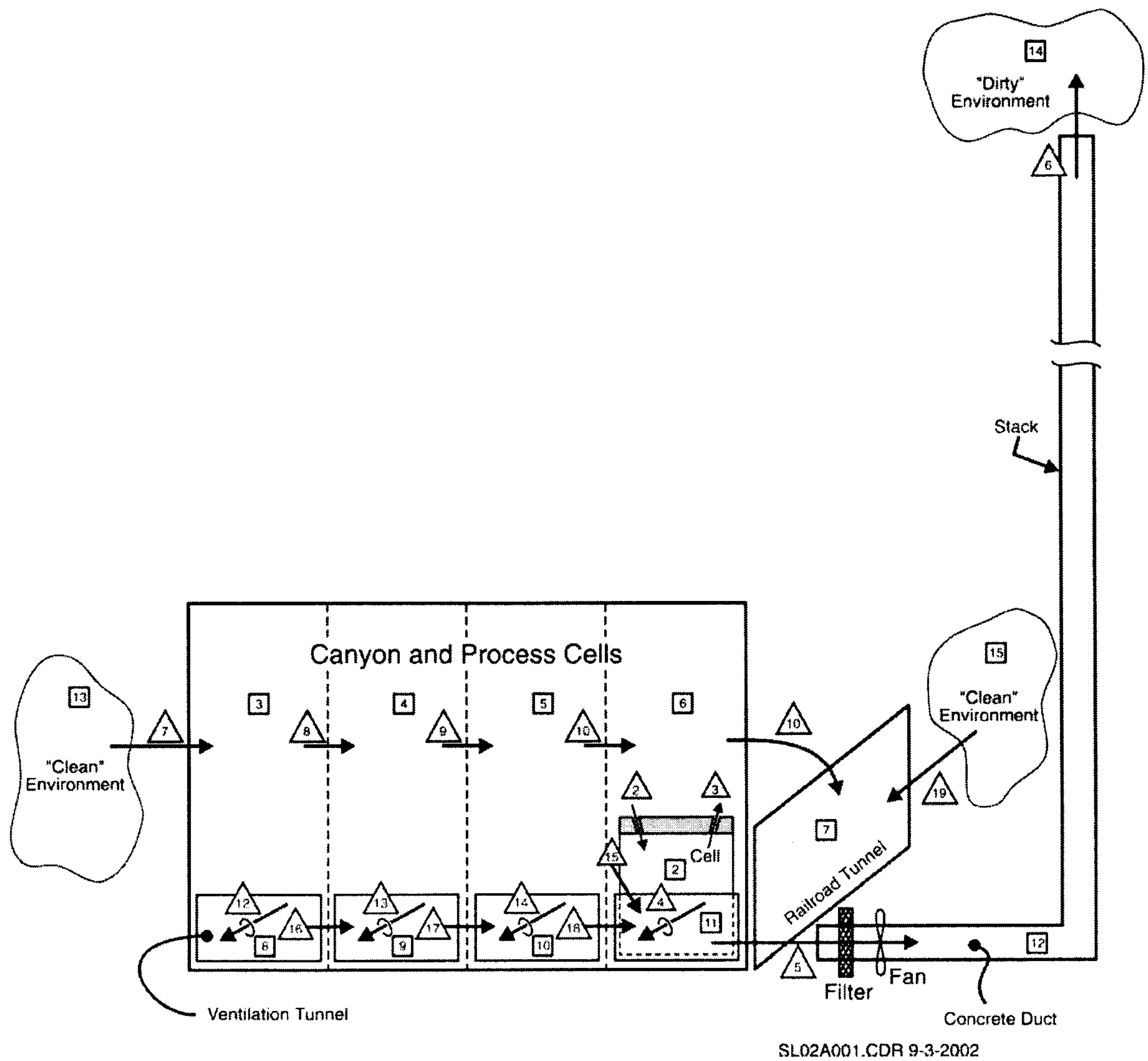
5.3 Validation of Selected FATE Model Improvements

Appendix C contains FAI memoranda describing improved FATE™ computer code models for modeling sludge behavior during transportation and storage.

Sections C.1 through C.3 describe the theoretical basis for global natural circulation between standard cells and the canyon in T Plant, implementation and testing of the model for FATE Quality Assurance, and an example application demonstrating that the circulation flow predicted by FATE is in agreement with a simple hand calculation. The important conclusion of these memos is that such global circulation will exist, which is beneficial in achieving low hydrogen concentrations in a cell.

Sections C.4 and C.5 describe the theoretical basis for natural convection heat transfer around the bottom head of an STSC, and implementation and testing of the model in FATE for FATE Quality Assurance. The important conclusion of these memos is that the holes in the STSC skirt are sufficient to credit this heat removal process, which is beneficial for thermal stability of sludge.

Figure 5-1: T Plant Nodalization Used by (Loscoe, 2003)



6.0 CALCULATION

6.1 STSC Model Representation

Figure 6-1 and Figure 6-2 show the FATE model for the STSC and sludge for the cases of settler sludge and container sludge respectively. Table 6-1 and Table 6-2 provide the corresponding list of regions, junctions, and heat sinks. For settler sludge, there is an annular insert that is water-filled in order to reduce the conduction length and the peak sludge temperature. The settler sludge volume is 0.5 m^3 in all cases examined here, corresponding to one loaded batch. This insert is not necessary for other container sludge. A volume of 1.6 m^3 of KW container sludge is loaded into the STSC, corresponding to two batches. Two-dimensional axisymmetric heat conduction in sludge is modeled using 20 stacks of short disk heat conductors connected vertically for conduction, 10 in the cylindrical part and 10 in the bottom head of STSC. Each heat conductor has 20 radial nodes. Hence, each heat conductor node is approximately 3.7 cm in radial extent and 7.0 cm in height.

Corresponding to each sludge heat conductor layer, the STSC wall is modeled as separate heat conductors. Heat generated in the sludge is conducted radially out to the STSC wall, where it is lost by convection and radiation to the cell atmosphere. Heat is also conducted vertically upward to the sludge top, where it is removed by overlying water.

Convection and radiation beneath the skirt are modeled because the holes in the STSC skirt promote effective natural circulation, see Appendix C.

Sludge initial composition and properties are based on the assumption that materials stratify upon loading. In this case, sludge is modeled as a series of metal-bearing and metal-free layers, one pair of such layers per batch loaded. The elevations and volumes of the individual sludge heat conductors are selected so cases of varying numbers of batches may be exactly achieved, and so that the volumes of metal-bearing and metal-free layers indicated in Table 3-1 and Table 3-2 can be well-approximated.

Details of selected inputs are discussed in Appendix A. Input files that contain these inputs are listed in Appendix B.

Figure 6-1: FATE Model Representation for the STSC with Settler Sludge.

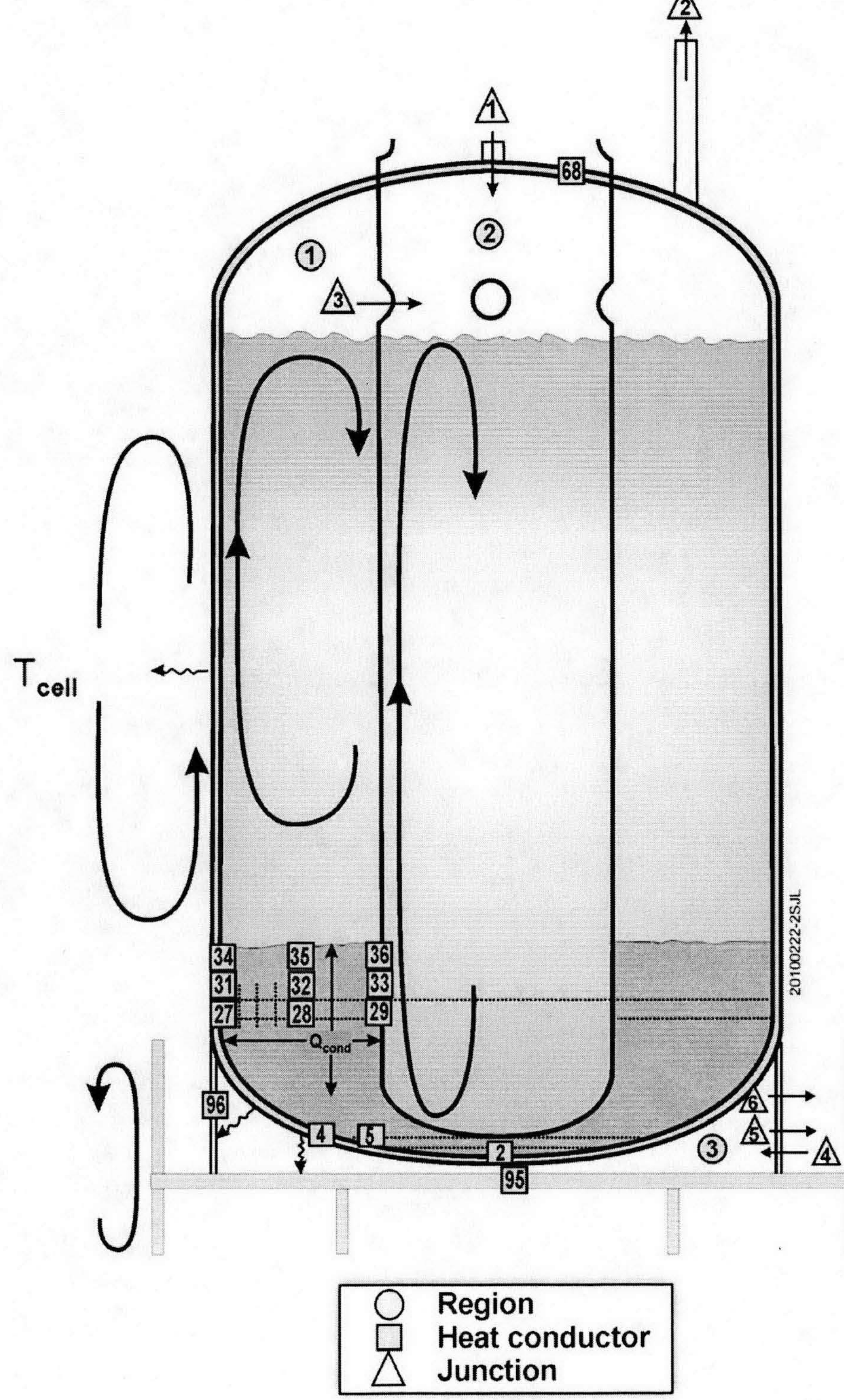


Figure 6-2: FATE Model Representation for the STSC with KW Container Sludge.

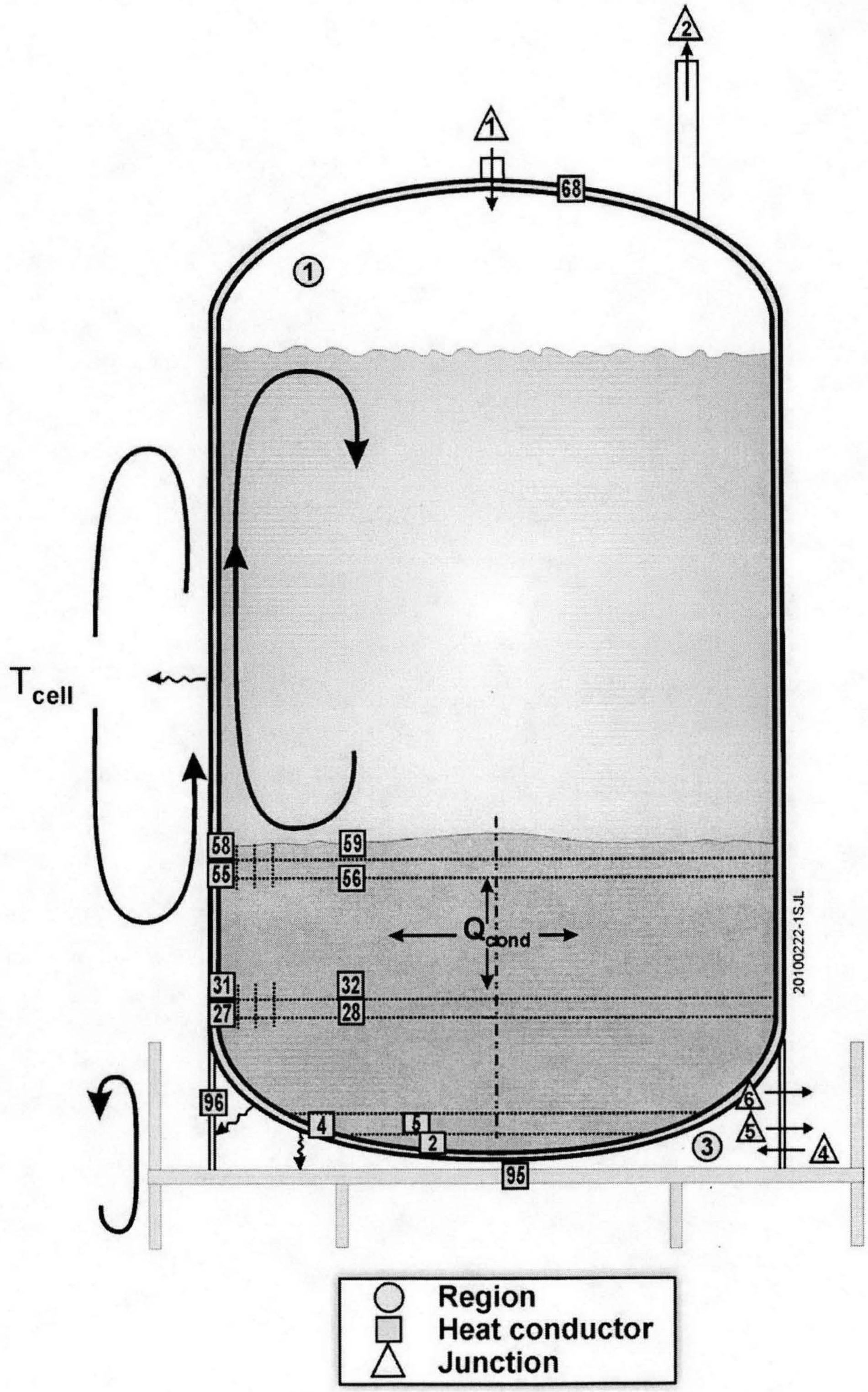


Table 6-1: FATE STSC Nodalization for Settler Sludge

Regions	
1	Main, annular section holding sludge
2	Insert section
3	Exterior, Inside Skirt
Junctions	
1	Open, unfiltered inlet, cell to insert section
2	Open, unfiltered outlet, main section to cell
3	Main to insert section
4	Cell to inside skirt, bottom half-circular holes
5	Cell to inside skirt, lower circular holes
6	Inside skirt to cell, upper circular holes
Heat Sinks	
1, 4, 7, … 34	STSC bottom head and cylindrical wall adjacent to sludge
2, 5, 8, … 35	Sludge
7, 10, 13, … 36	Insert wall adjacent to sludge
61	Insert wall above sludge in contact with water and gas
63	STSC wall above sludge in contact with water and gas
68	STSC top head
95	Secondary containment structure in cell
96	STSC support skirt

Table 6-2: FATE STSC Nodalization for KW Floor Sludge

Regions	
1	STSC interior
3	Exterior, Inside Skirt
Junctions	
1	Open, unfiltered inlet, cell to STSC interior
2	Open, unfiltered outlet, STSC interior to cell
4	Cell to inside skirt, bottom half-circular holes
5	Cell to inside skirt, lower circular holes
6	Inside skirt to cell, upper circular holes
Heat Sinks	
1, 4, 7, ... 58	STSC bottom head and cylindrical wall adjacent to sludge
2, 5, 8, ... 59	Sludge
63	STSC wall above sludge in contact with water and gas
68	STSC top head
95	Secondary containment structure in cell
96	STSC support skirt

6.2 T Plant Model Representation

The T Plant model representation is designed to allow cases with and without active ventilation, cases with the detailed STSC model residing in a standard cell or cell 2R, and cases with a variable number of cells containing STSCs. In particular, the model is designed to represent the potential for natural convection loops between cells and the canyon in the absence of ventilation. The region and junction nodalization is shown in Figure 6-3 and listed in Table 6-3: FATE T Plant Nodalization, Regions and Junctions. Heat sinks are listed in Table 6-4. Details of selected inputs are discussed in Appendix A. With respect to flow paths (junctions), please note that the direction indicated by arrow heads in figures is nominal, and that the FATE program mechanistically determines not only the direction of flow but whether or not countercurrent flow occurs along the path.

As mentioned above, one STSC is modeled in detail. This STSC may be placed in either a standard cell, Region 6 in Figure 6-3, or cell 2R, Region 11 in Figure 6-3. Sources of heat and hydrogen gas from other STSC are approximated by constant values, see Appendix A. The STSC loses heat by convection and radiation to the cell gas, which in turn transfers heat to the walls and cover blocks modeled as one-dimensional heat conductors. Since the floor is cooler, it can be neglected.

Except for cell 2L, each cell region has a cover block flow path to the canyon, and the pipe trench also has a cover block flow path. Standard cells and the pipe trench have 10" flow paths to the ventilation duct. Cells 2L and 2R have 10" flow paths to a 24" buried pipe external to the plant. For cases with ventilation, the flows into cell regions and the pipe trench depend upon the cover block resistance input value. For cases without ventilation, the model will automatically calculate flow direction and whether or not there can be countercurrent flow.

Heat sinks assigned to each region are of greater importance in cases without ventilation than with ventilation because heat transfer from air to walls affects the gas density. Cell walls are modeled with external insulated boundary conditions as an approximation. The same applies to the ventilation duct and pipe trench. The wall between cells 2L and 2R is modeled with convection to both cells. The 24" pipe wall and surrounding ground are represented.

Figure 6-3: T Plant Model Representation, Regions and Junctions.

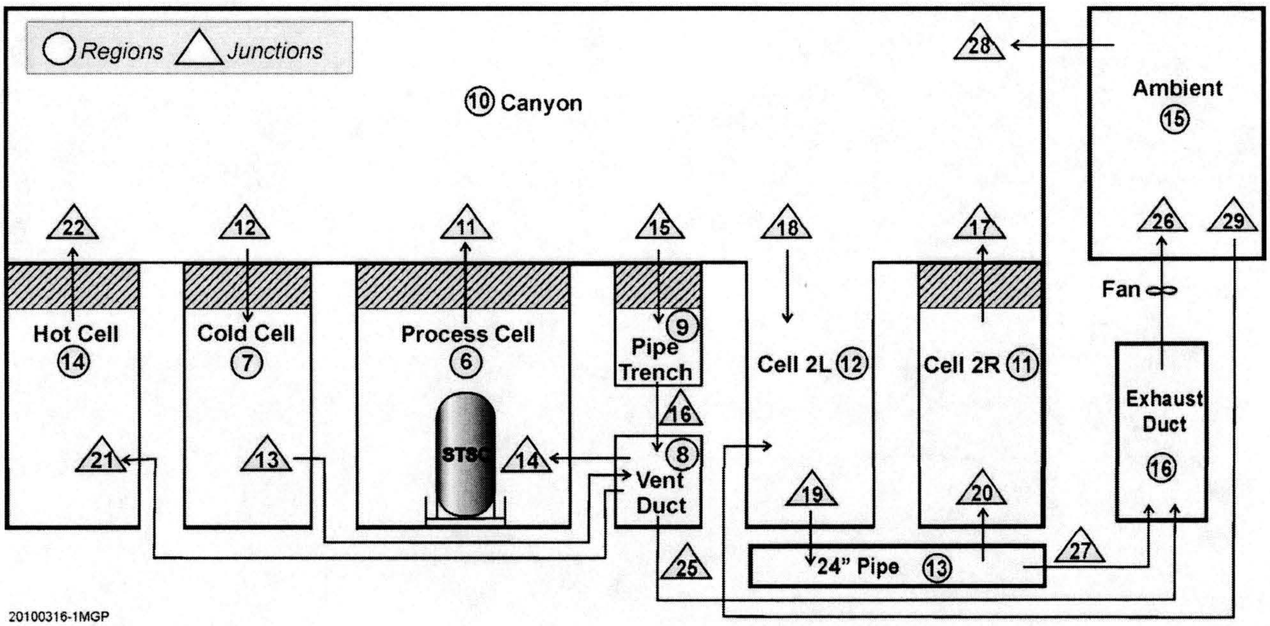


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Table 6-3: FATE T Plant Nodalization, Regions and Junctions

Regions	
6	Standard process cell, holds "active" STSCs for standard cell cases
7	Cold (empty) standard process cells
8	Ventilation duct
9	Pipe trench
10	Canyon
11	Cell 2R, holds STSCs for long cell cases
12	Cell 2L
13	24" duct segment connecting cells 2L and 2R
14	Hot (holding other STSCs) standard process cells
15	Ambient
16	Exhaust duct used for cases with ventilation
Junctions	
11	Process cell to canyon, cover block gaps
12	Canyon to cold cells, cover block gaps
13	Cold cells to ventilation duct, 10" path
14	Ventilation duct to process cell, 10" path
15	Canyon to pipe trench, cover block gaps
16	Pipe trench to ventilation duct, 10" path
17	Cell 2R to canyon, cover block gaps
18	Canyon to cell 2L, open area
19	Cell 2L to 24" duct segment, 10" path
20	24" duct segment 10 cell 2R, 10" path
21	Ventilation duct to hot standard cells
22	Hot standard cells to canyon
25	Ventilation duct to exhaust duct
26	Exhaust duct to ambient, fan junction
27	24" duct segment to exhaust duct
28	Leakage from ambient to canyon
29	Leakage from ambient to cell 2L through railroad tunnel

Table 6-4: FATE T Plant Nodalization, Heat Sinks

Heat Sinks	
101	Process cell (6) "long side" walls to neighbor cells (insulated)
102	Process cell (6) "short side" walls to galleries and trenches (insulated)
103	Process cell (6) cover blocks, convects to canyon
106	Cold cell (7) "long side" walls to neighbor cells (insulated)
107	Cold cell (7) "short side" walls to galleries and trenches (insulated)
108	Cold cell (7) cover blocks, convects to canyon
111	Cell 2R (11) "long side" wall to standard cells (insulated)
112	Cell 2R (11) "short side" walls to galleries and ground (insulated)
113	Cell 2R (11) cover blocks, convects to canyon
114	Cell 2R (11) "long side" wall to cell 2L, convects to 2L
116	Cell 2L (12) "long side" wall to cell 1L (insulated)
117	Cell 2L (12) "short side" walls to galleries and ground (insulated)
121	Ventilation duct (8) lengthwise walls (insulated)
122	Pipe trench (9) lengthwise walls (insulated)
123	Pipe trench (9) cover blocks, convects to canyon
124	Wall of 24" pipe connecting 2L and 2R, sandwiched to ground
125	Ground outside 24" pipe
126	Hot cell (14) "long side" walls to neighbor cells (insulated)
127	Hot cell (14) "short side" walls to galleries and trenches (insulated)
128	Hot cell (14) cover blocks, convects to canyon
131	Canyon (10) lower section lengthwise exterior wall, convects to ambient
132	Canyon (10) upper section lengthwise exterior walls, convects to ambient
133	Canyon (10) lower section lengthwise interior wall (insulated)

6.3 Sludge Interim Storage Cases

Table 6-5 lists the cases calculated. There are three main attributes distinguishing the cases:

1. Sludge type, volume, and STSC geometry. For settler sludge the volume is always 0.5 m^3 and the STSC geometry includes the insert per Figure 6-1. For KW container sludge the volume is always 1.6 m^3 and the STSC does not have an insert, Figure 6-2.

2. Cell containing the STSC. The STSC is placed in either a standard cell from the cell range 3 through 20 inclusive (region 6 of Figure 6-3), or else in cell 2R (region 11 of Figure 6-3). There are always 6 STSCs in a standard cell and 8 STSCs in a long cell.

3. T Plant Ventilation. Cases with and without T Plant ventilation are considered. With ventilation, the ventilation rate per cell is determined by the relative flow resistances as discussed in Appendix A. With no ventilation, the stack effect for T Plant is conservatively ignored, so that there is no overall inflow to the canyon, through the cells, and up the stack. While this is conservative, it is also a potentially real situation depending upon the relative ambient and interior temperatures and pressures. The model will predict natural circulation flows between cells and the canyon based upon input flow resistances and elevations, and density differences that evolve during the calculation.

In all cases, the following attributes are identical:

1. Sludge is stratified into metal-bearing and metal-free layers per added batch.
2. Safety basis sludge properties are used.
3. Overlying water is filled to the level given in Figure 3-1.
4. The U-H_2O rate law multiplier is set to the safety basis value of 3.0.
5. Sources of heat and hydrogen generation from additional STSCs in a process cell are approximated by constant values, see Appendix A.

Table 6-5: Sludge Interim Storage Cases Calculated.

Analysis	Name and Input Files[1]	Sludge Type	Sludge Volume[2]	STSC Geometry	Ventilation	Cell Type
1a	CONTRF1	KW floor	1.6 m^3	No insert	Yes	Standard
1b	CONTLF1	KW floor	1.6 m^3	No insert	Yes	2R
2a	CONTRN1	KW floor	1.6 m^3	No insert	No	Standard
2b	CONTLN1	KW floor	1.6 m^3	No insert	No	2R
3a	SETTRF1	Settler	0.5 m^3	Insert	Yes	Standard
3b	SETTLF1	Settler	0.5 m^3	Insert	Yes	2R
4a	SETTRN1	Settler	0.5 m^3	Insert	No	Standard
4b	SETTLN1	Settler	0.5 m^3	Insert	No	2R

(1) Each case has two input files, a "case file" and a "base file" The case input file name is the same as the case name. The naming convention for cases and files is as follows:

Case name and case file. The case file defines case-specific boundary conditions including the cell geometry and sludge properties. The naming convention uses letter groupings as follows:

Initial 3 letters: CON for KW floor (containerized), SET for settler sludge,

Letter 4: T for T Plant cell,

Letter 5, Cell type: R = regular, i.e. standard (cells 3 through 20), L = long (cell 2R), and

Letter 6, Ventilation type: F = T Plant fans running, N = no fans.

Letter 7, Version number: 1

Base file. The base file contains defines the STSC geometry and the geometry of heat conductors representing the sludge. The base file for all KW floor sludge cases (1a through 2b) is CON2STSC1.dat. The base file for all settler sludge cases (3a through 4b) is SET1STSC1.dat.

(2) Sludge is stratified into metal-bearing (lower) and metal-free (upper) layers. In all KW floor sludge cases there are 2 pairs of layers corresponding to 2 batch loadings. In the settler sludge case there is one batch and one pair of layers.

7.0 RESULTS AND CONCLUSIONS

7.1 Results Description

Calculation results are summarized in Table 7-1. Transient results plots provide histories of process variables, with three pages per case as listed in the table. Comparisons between peak quantities are shown in Figure 7-1 through Figure 7-3.

In all cases the transient duration simulated is 20 days. This duration is sufficient to allow maxima in sludge temperature, hydrogen generation rate, and STSC and cell hydrogen concentrations. Transient plots per case, listed in Table 7-1, present the following general information, and case-specific comments will follow this list:

Page 1, Upper Left: Gas concentration in the STSC.

Page 1, Upper Right: Sludge temperature, °C.

Page 1, Lower Left: Gas, water, and cell wall temperatures, °C.

Page 1, Lower Right: Gas flow through the STSC vent, kg/s. Since the gas density is about 1 kg/m^3, this is numerically about the volumetric flow rate in m^3/s.

Page 2, Upper Left: Sludge heat source, W.

Page 2, Upper Right: Cases with ventilation, canyon pressure, Pa (to convert to inches water gage, divide by 249). Cases without ventilation, gas flow rate through cover blocks, kg/s (to convert to cfm, multiply by approximately 2100).

Page 2, Lower Left: Hydrogen source rate, L/day. The STSC headspace is about 470 L, and cell free volume is about 114 m^3.

Page 2, Lower Right: Cell gas concentrations.

Page 3, Upper Left: Gas temperatures in canyon and cells.

Page 3, Upper Right: Gas flows within T-Plant.

Page 3, Lower Left: Gas temperatures in ambient and vent paths.

Page 3, Lower Right: Gas flow between T-Plant and environment (e.g. air infiltration).

Table 7-1: Transient Results Summary for KW Floor Sludge Shipping in an STSC.

Case	Name	Thermal Stability	Peak Sludge Temperature [°C]	Peak Power [W]	Peak H_2 Rate [liter/day]	Peak H_2 Concentration in Cell [%]	Peak H_2 Concentration in STSC [%]	Figures
1a	CONTRF1	Stable	60°C at 16d	195	830	<0.1	1.6	7-4,5,6
1b	CONTLF1	Stable	58°C at 16d	190	770	<0.1	1.5	7-7,8,9
2a	CONTRN1	Stable	72°C at 15d	270	1300	1.0	3.3	7-10,11,12
2b	CONTLN1	Stable	67°C at 16d	240	1150	1.5	3.1	7-13,14,15
3a	SETTRF1	Stable	53°C at 8d	190	670	<0.1	1.3	7-16,17,18
3b	SETTLF1	Stable	52°C at 8d	190	640	<0.1	1.4	7-19,20,21
4a	SETTRN1	Stable	61°C at 9d	230	960	1.0	2.8	7-22,23,24
4b	SETTLN1	Stable	57°C at 10d	210	830	1.5	3.0	7-25,26,27

Figure 7-1: Peak Hydrogen Concentration in Cell

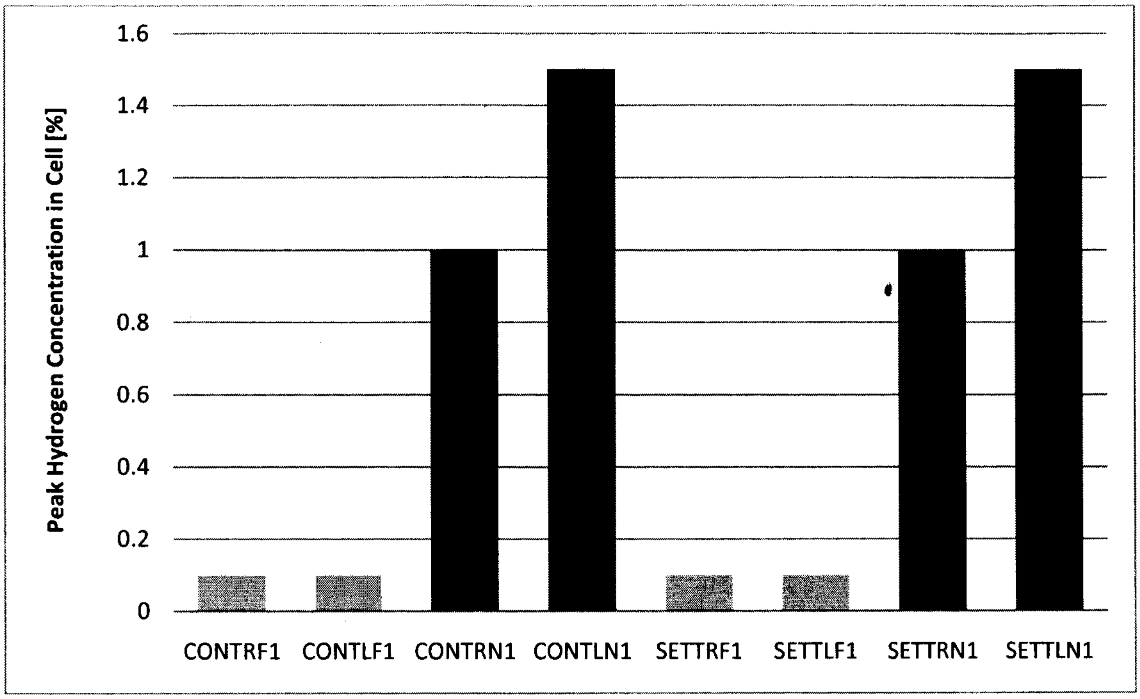


Figure 7-2: Peak Sludge Temperature

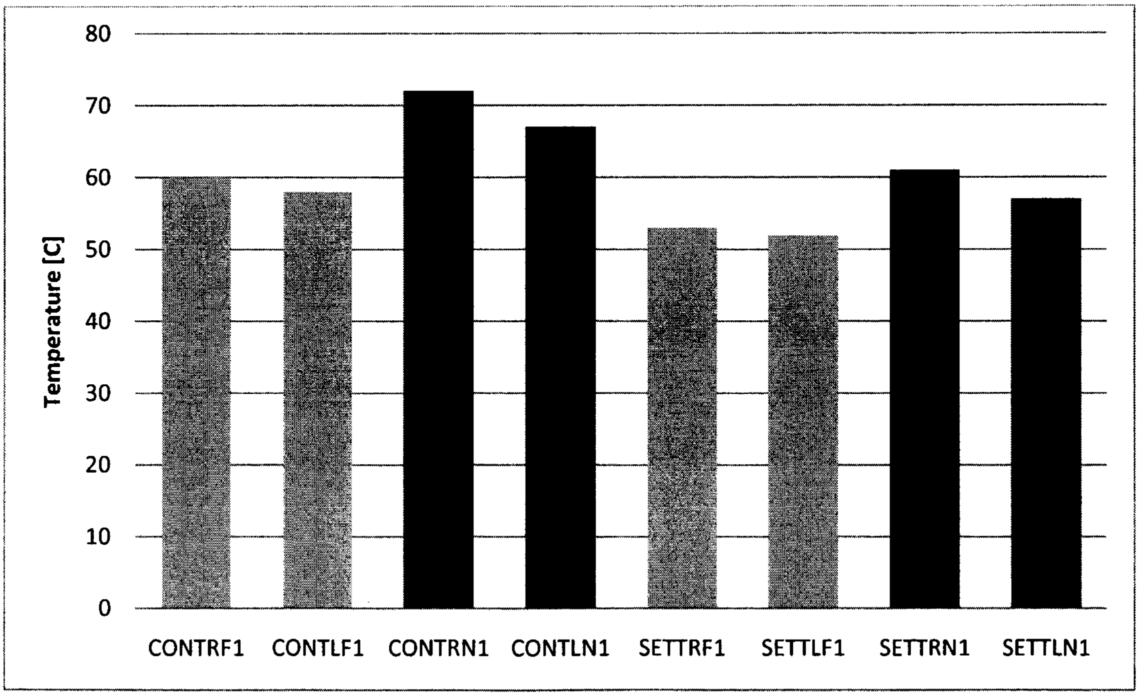
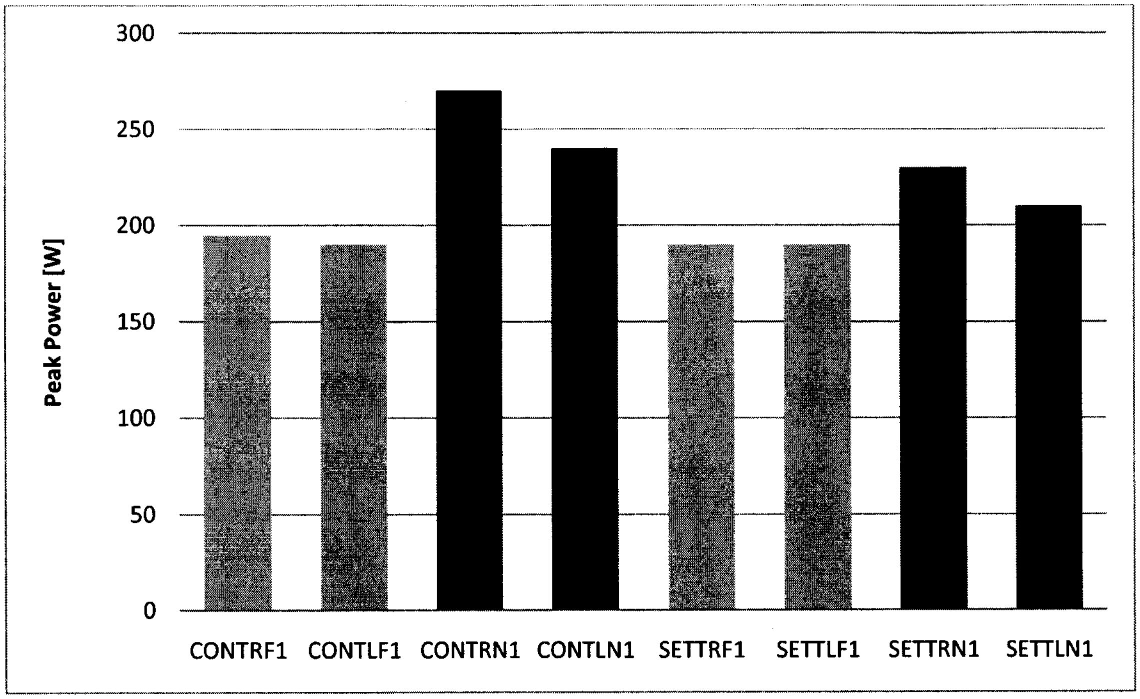


Figure 7-3: Peak Total Power in STSC



KW container sludge cases with ventilation CONTRF1 (standard cell) and CONTLF1 (long cell) progress in virtually the same manner, differing only slightly in absolute quantities (temperature, hydrogen concentration, etc.); see Figure 7-4 through Figure 7-9. Temperatures slowly rise with peak sludge temperature peaking at 60 °C at around 16 days. The hydrogen generation rate peaks at about 15 days, and the hydrogen concentration in the STSC peaks around 1.6%. The reason for maxima in temperatures and hydrogen concentrations is that uranium metal is consumed by the oxidation reaction. Reaction rates increase with temperature but decrease as metal is consumed.

Hydrogen does not accumulate in the cell in any appreciable amount for these cases with ventilation. The ventilation flow is about 450 cfm per cell. This ventilation rate may be somewhat overestimated, because the pipe trench flow should be about half the total flow into the standard cells, but it is lower than expected. This is likely due to the given the cover block gap assumptions, but revising the relative flow resistances will not influence the overall conclusions. Gas and water temperatures exhibit periodic variation due to ambient diurnal temperature variation. A similar but lesser variation occurs in STSC gas concentrations. After 15 days, the water temperature sometimes exceeds the gas temperature, so that increased evaporation affects the steam concentration.

The corresponding cases without ventilation CONTRN1 and CONTLN1 are also very similar to each other; see Figure 7-10 through Figure 7-15. The main differences between these "fans off" cases and the previous "fans on" cases (CONTRF1 and CONTLF1) are the accumulation of steam and hydrogen in the cell (up to 1.5% H_2) and the earlier, higher peaks in temperature, power, and hydrogen generation rate. The sludge temperature in fans off cases is about 10 °C higher than in fans on cases.

In these cases without ventilation, hydrogen generated in the process cell and the other hot cells containing STSCs is lost by upflow to the canyon (see for example Figure 7-12, upper right). This flow is partially supplied by downflow from the canyon to cold standard cells and then into the ventilation duct, and partially by downflow through cell 2L and via the 24 inch pipe and exhaust duct to the ventilation duct. The contribution from cell 2L is comparable to that of all the cold standard cells combined because cell 2L has no cover block resistance. It is interesting to note that exchange flow between the canyon and ambient through infiltration paths has no net effect on internal circulation in these fans-off cases.

Settler sludge cases with ventilation SETTRF1 (standard cell) and SETTLF1 (long cell) exhibit peak sludge temperatures about 10 °C lower than in the KW container sludge cases, and peaking at earlier at around 8 days at 52-53°C (see Figure 7-16 through Figure 7-21.) Fans provide adequate ventilation to prevent an appreciable quantity of hydrogen from building up in the cell. The two cases are very similar in progression and timing. As with container sludge cases, diurnal ambient temperature variation influences the gas and water temperatures, and the STSC steam concentration is affected by evaporation as well.

Corresponding cases without ventilation SETTRN1 and SETTLN1 (see Figure 7-22 through Figure 7-27) show temperatures rising about 10 °C higher than in fans on cases, also at around 8 days. The hydrogen concentration in the STSC peaks at about the same time ranging between 2.8% and 3.0%, depending on cell size. Due to the insert, there is in general more heat transfer from sludge to water in settler sludge cases than in KW container cases, and without ventilation the water temperature exceeds the STSC gas temperature after about 8 days, leading to increased evaporation.

Ventilation availability plays the largest role in STSC thermal response. T-Plant ventilation is capable of cooling STSCs and removing hydrogen from the cell atmosphere. Without ventilation, the STSCs heat up more, and natural circulation through cover blocks is required to remove it from the cell.

The character of the sludge - volume, number of batches loaded, and material composition - plays the next most significant role in determining the thermal behavior of an STSC. The single-batch loading of settler sludge concentrates uranium metal in the lower head of the STSC where heat transfer is the lowest.

Cell size has the least effect on STSC thermal stability. Larger cells have more heat transfer area to the T-Plant's thick concrete walls which tends to remove more heat in cases without ventilation. The increased cell volume dilutes hydrogen released from the STSC, leading to a denser atmosphere than the standard cells in no ventilation cases. In the cases with ventilation, the heat load from the additional older STSCs tends to slightly increase the cell and sludge temperature.

This is the first calculation of sludge behavior at T Plant to employ a detailed building model that considers standard cells in various states, the long cells, and the pipe trench, and allows for natural circulation between the canyon and groups of cells. Actual flow and pressure balance conditions used at T Plant during contemporary operation may differ from what is documented in earlier references. Cover block gap resistances are based upon old specifications and selected field measurements of gaps at deck level. The flow split between cells with fans on and the circulation patterns and rates with fans off are affected by assumptions that underlie the flow resistance values input to the model. Also, circulation patterns and hydrogen concentrations with fans off are affected by the assumed number of STSCs in a given cell and the number of cells containing STSCs, because these affect cell gas densities via their heat and hydrogen sources. It is also possible that the initial cell conditions, reflecting time of year and the thermal lag between the ambient, canyon, and cells, could influence the flow pattern for fans-off cases. The assumptions built into the T Plant model and fans-off scenarios require further review to ensure that conservative selections have been made.

7.2 Conclusions

Conclusions of from the discussion of results are:

1. Sludge is thermally stable in all cases considered.
2. The cell and STSC hydrogen concentrations never exceed 4% for all cases.
3. The most important effect on results is ventilation versus no ventilation.
4. Results are nearly identical for standard cell and long cell cases; this is the least significant effect.
5. The worst cases examined are for container sludge with no ventilation, cases 2a and 2b, CONTRN1 and CONTLN1. For CONTRN1 the peak hydrogen concentration is 1.0% in the cell and 3.3% inside the STSC, and the peak sludge temperature is 72°C which occurs at day 15 of the scenario. The cell hydrogen concentration is slightly higher for CONTLN1, about 1.5%.
6. T plant flow conditions, flow resistances, and assumptions for fans-off scenarios should be reviewed to ensure that the contemporaneous configuration is correctly represented and that conservative scenarios have been identified.

7.3 Transient Results Figures

Transient results figures appear on the following pages.

Figure 7-4: Case CONTRF1 Transient Results History (1 of 3)

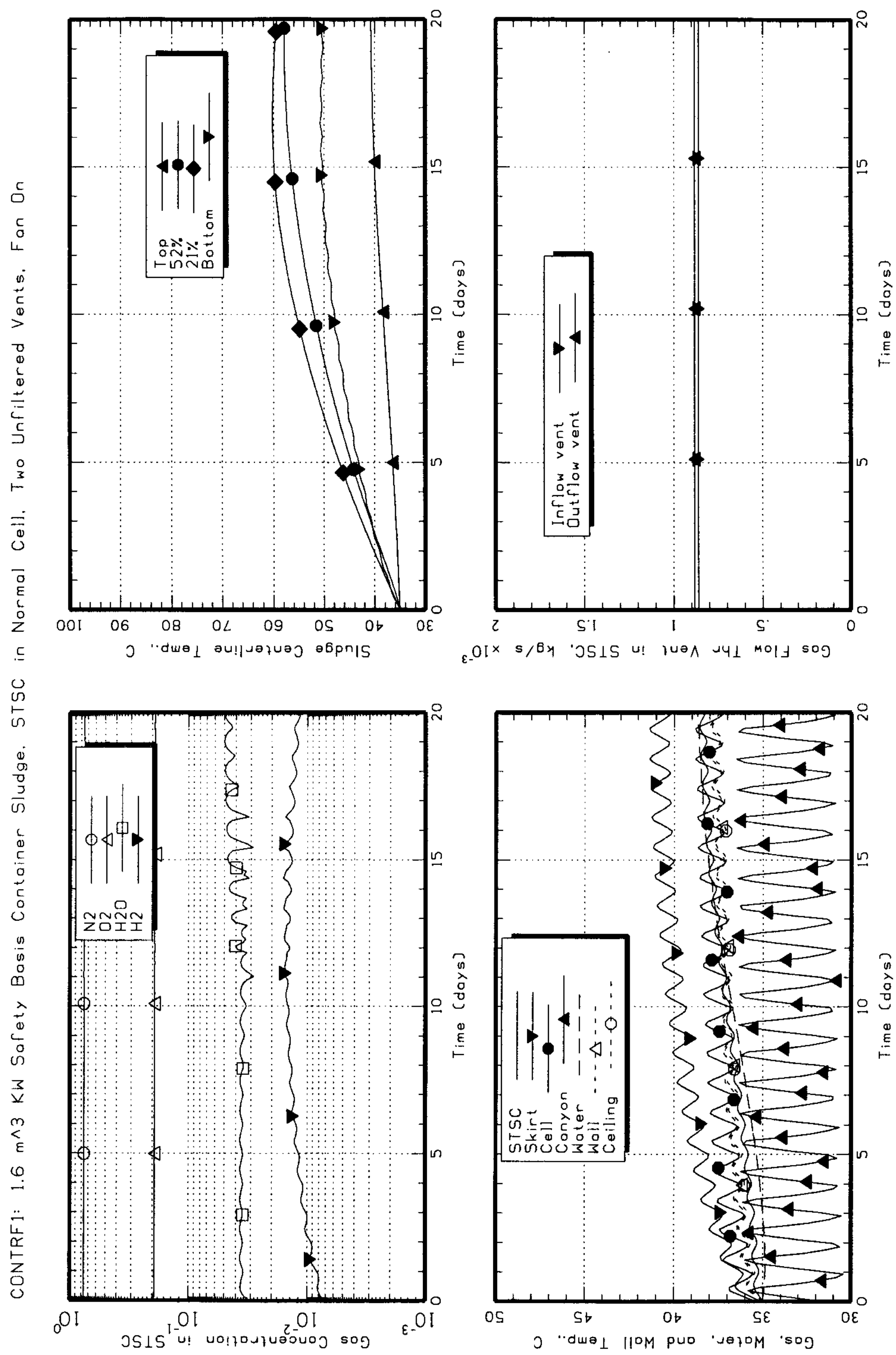


Figure 7-5: Case CONTRF1 Transient Results History (2 of 3)

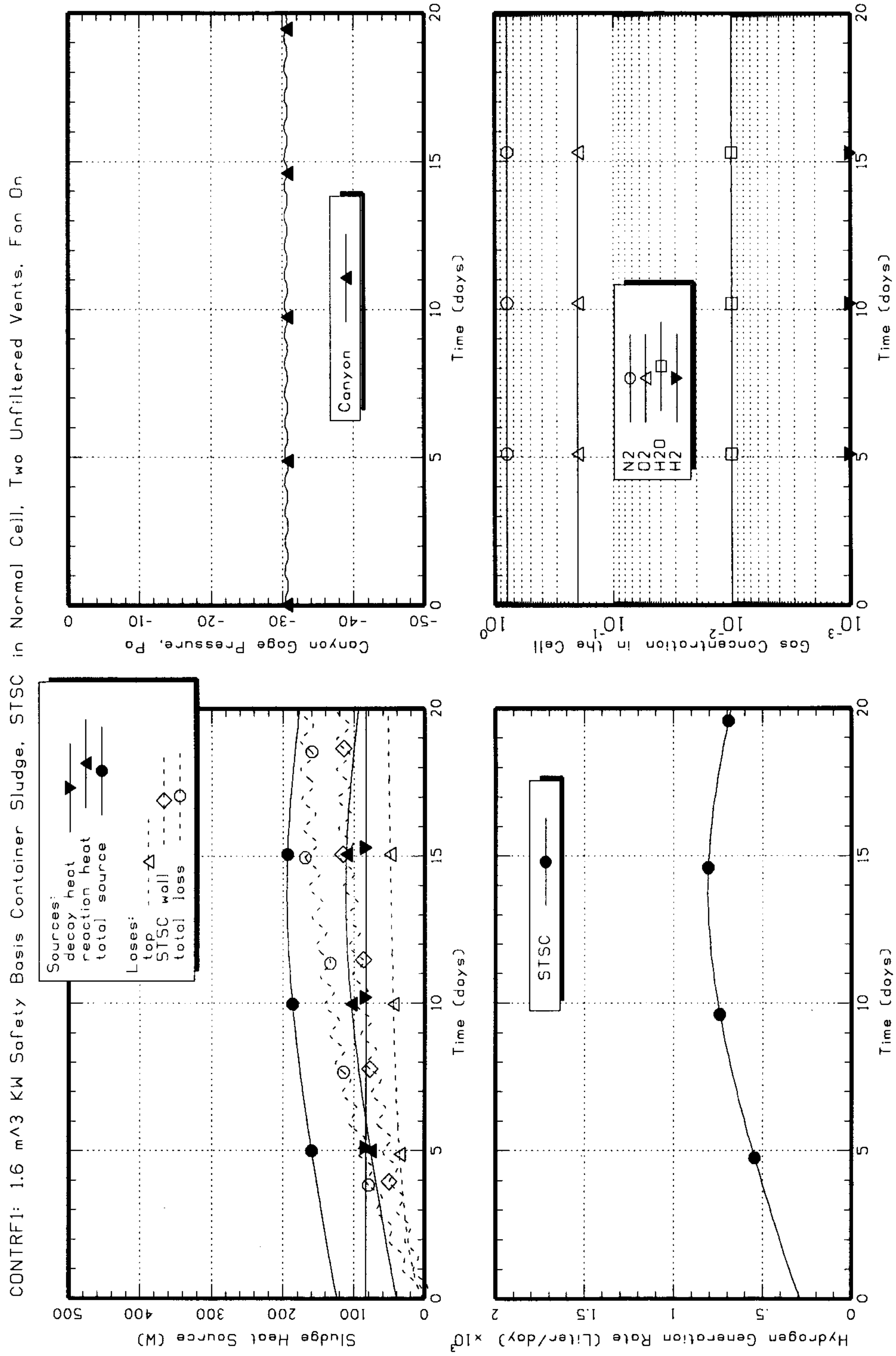


Figure 7-6: Case CONTRF1 Transient Results History (3 of 3)

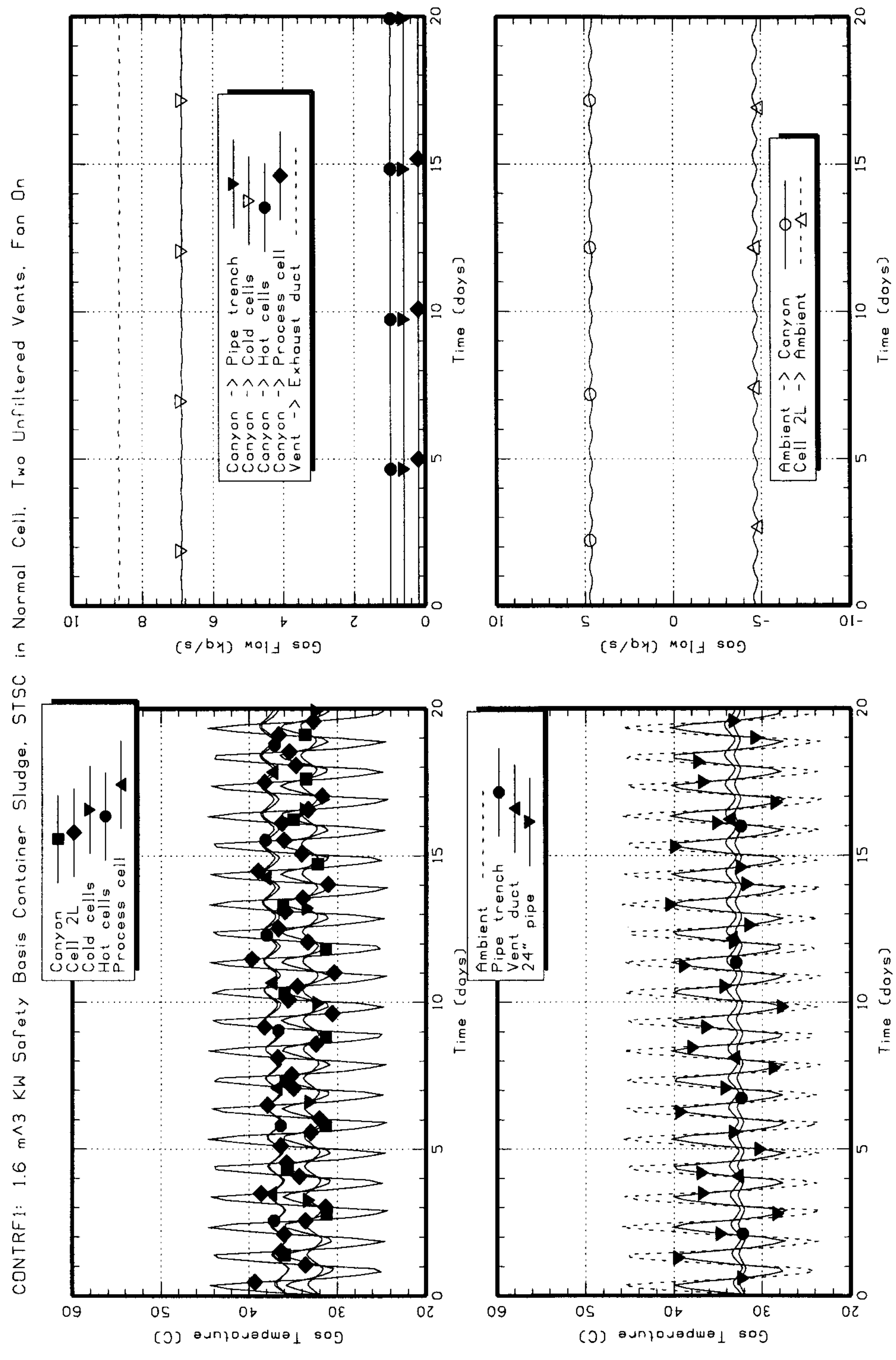


Figure 7-7: Case CONTLF1 Transient Results History (1 of 3)

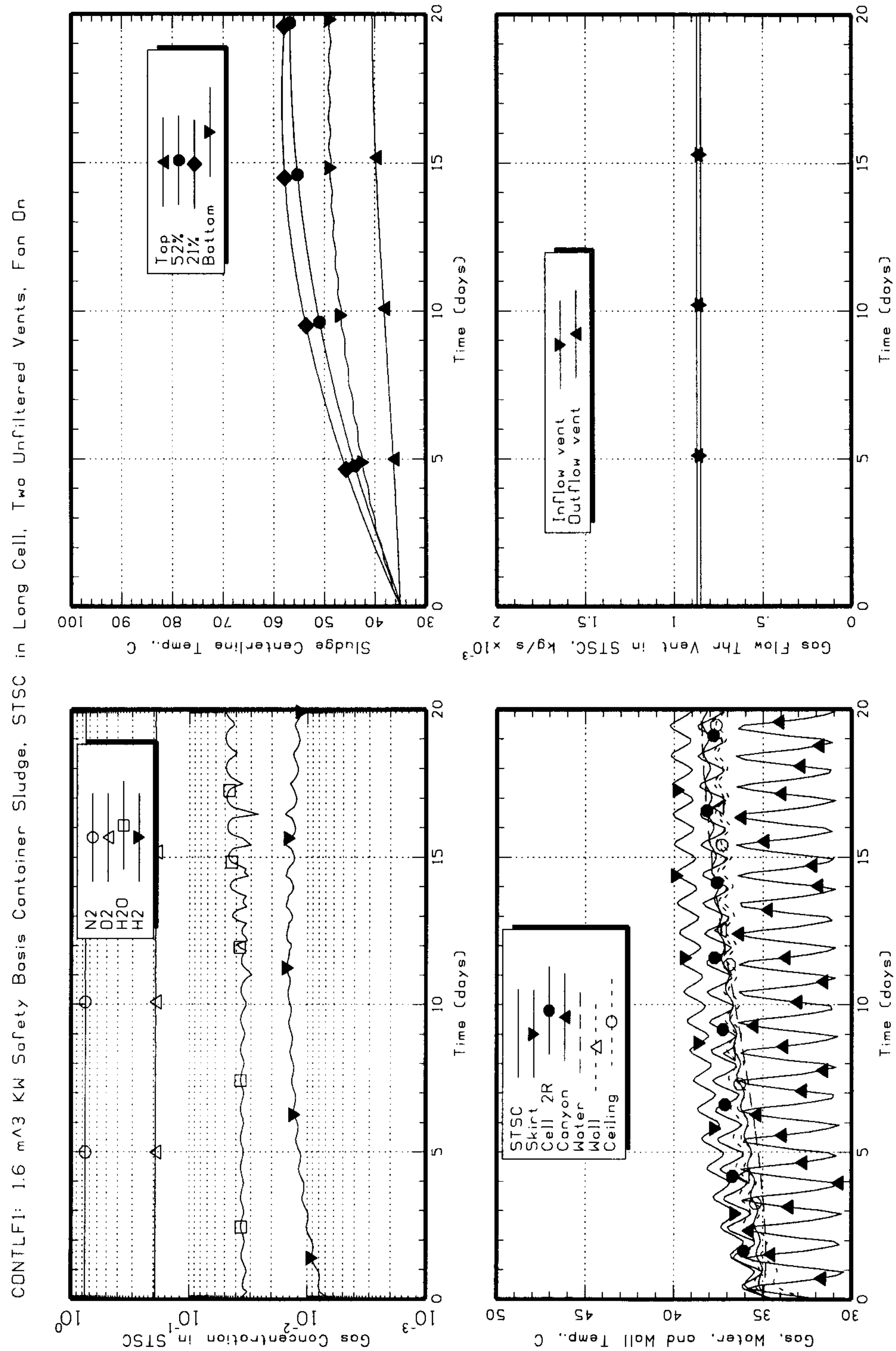


Figure 7-8: Case CONTLF1 Transient Results History (2 of 3)

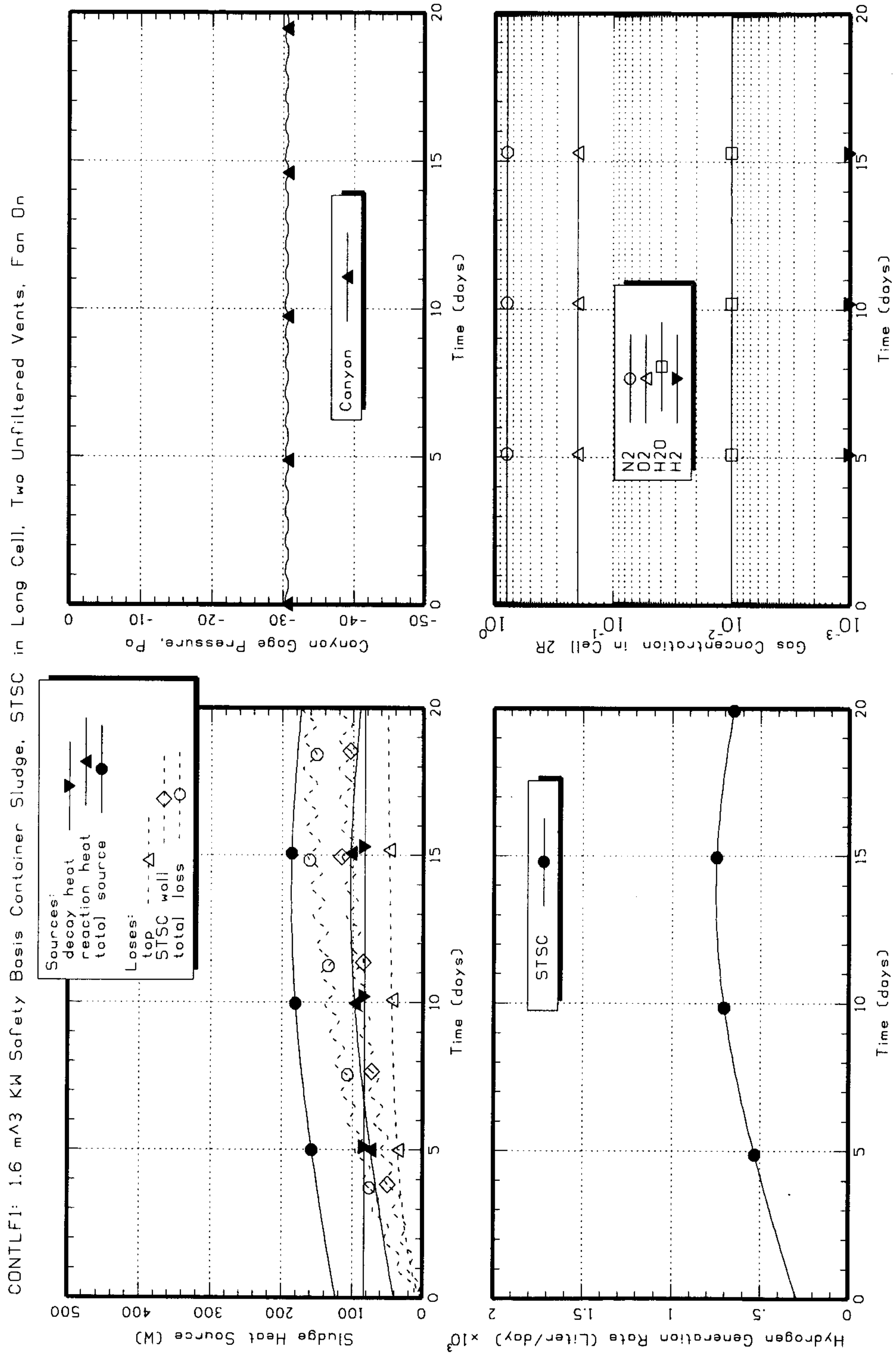


Figure 7-9: Case CONTLF1 Transient Results History (3 of 3)

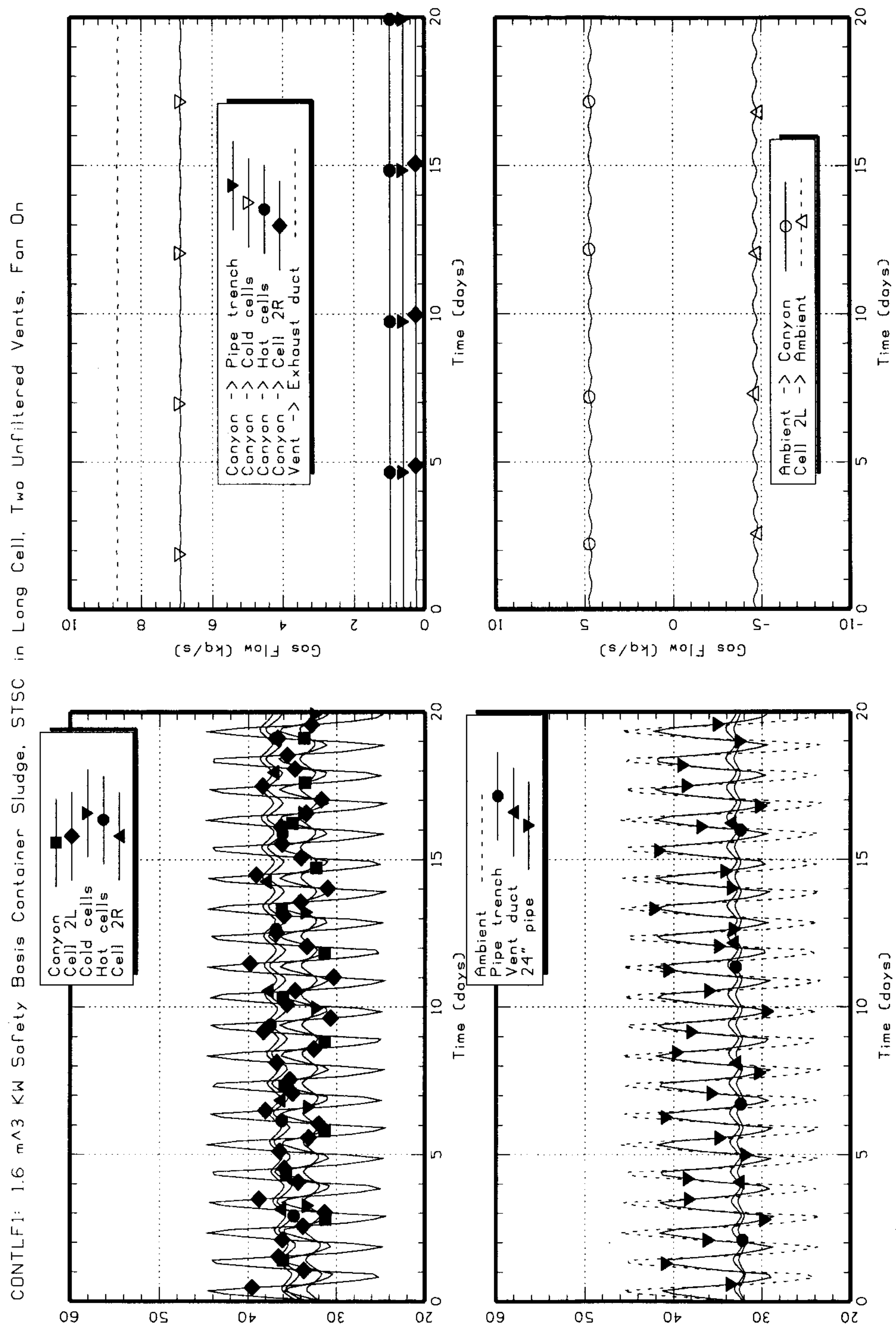


Figure 7-10: Case CONTRN1 Transient Results History (1 of 3)

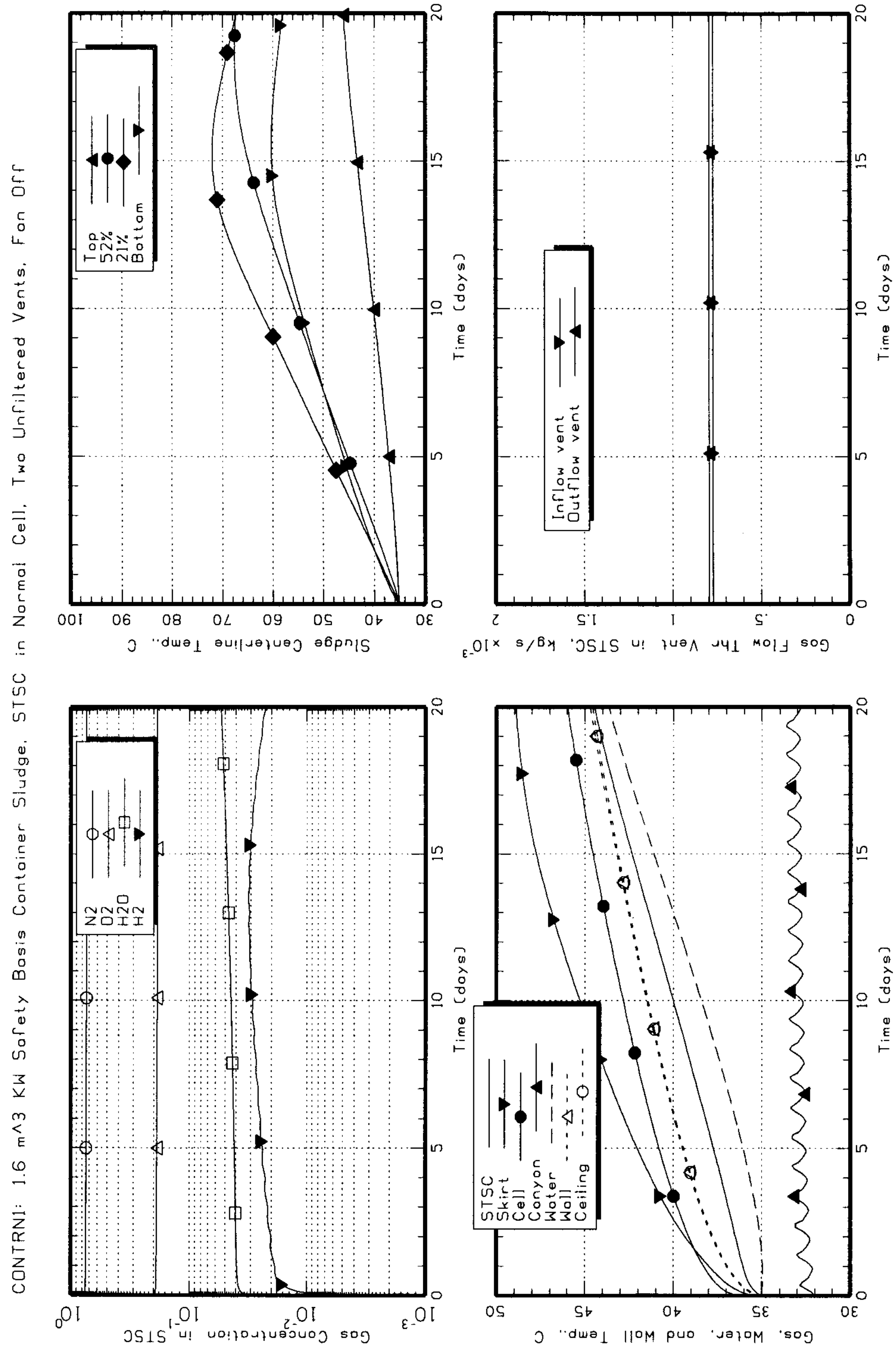


Figure 7-11: Case CONTRN1 Transient Results History (2 of 3)

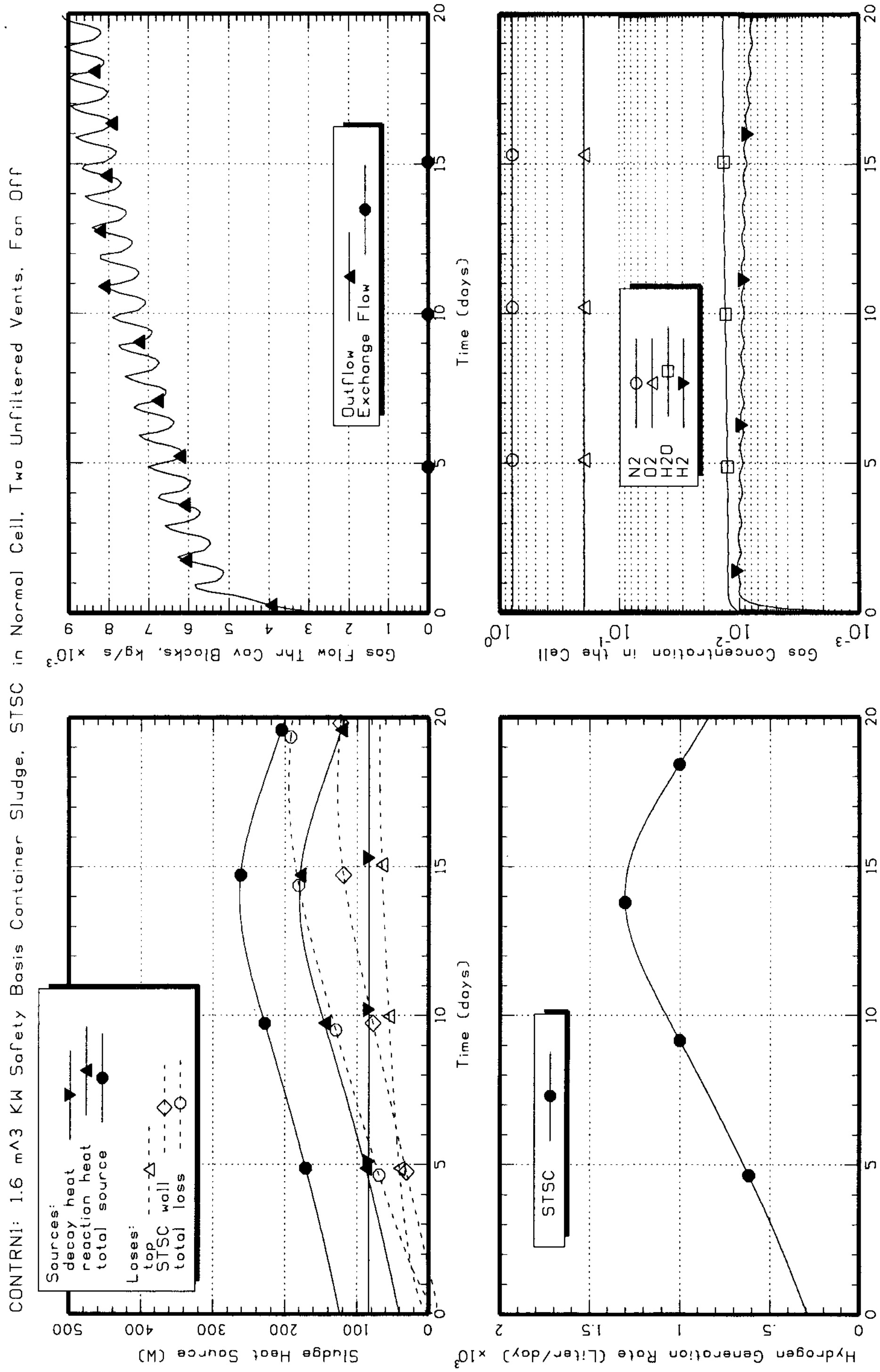


Figure 7-12: Case CONTRN1 Transient Results History (3 of 3)

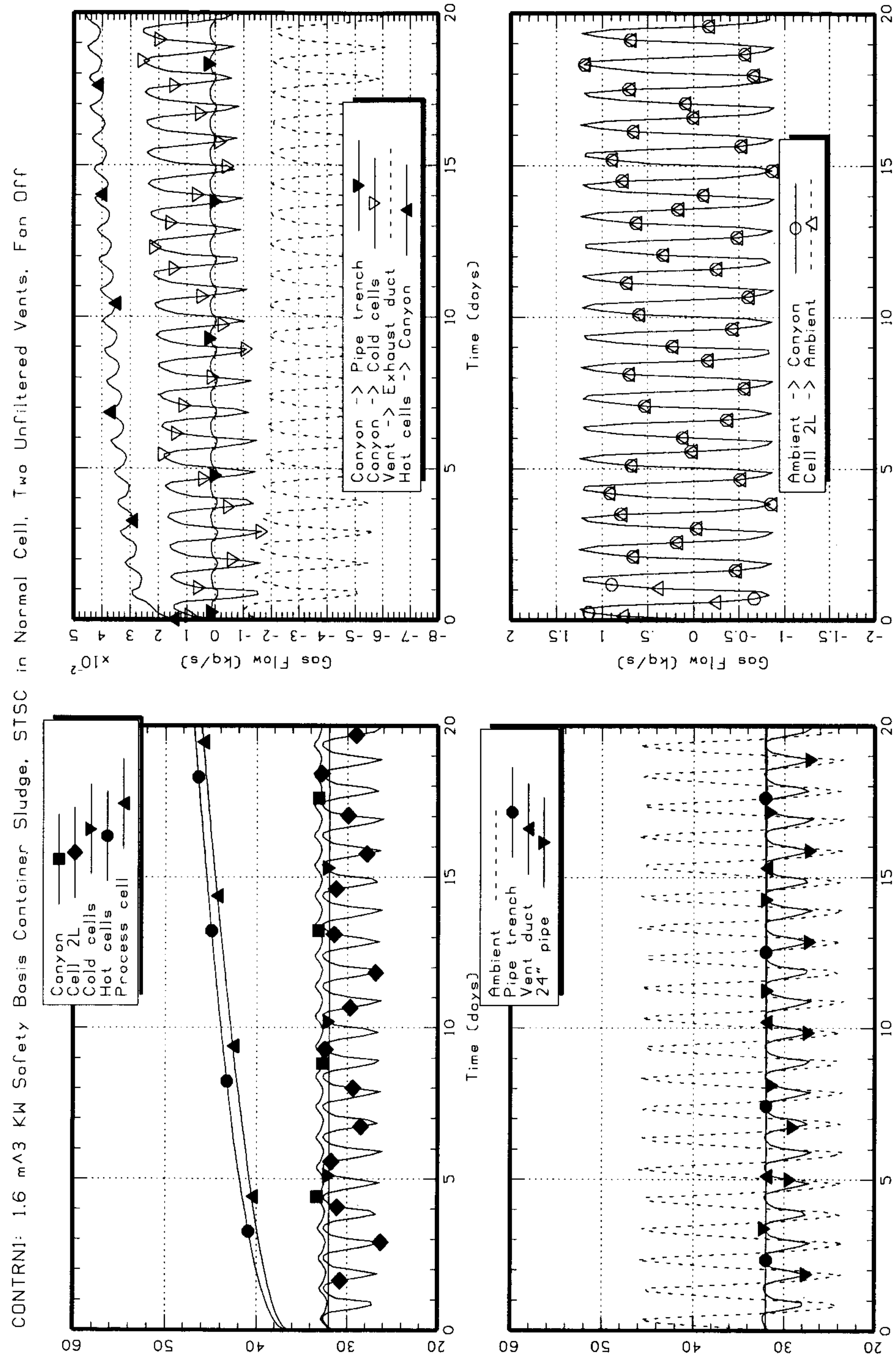


Figure 7-13: Case CONTLN1 Transient Results History (1 of 3)

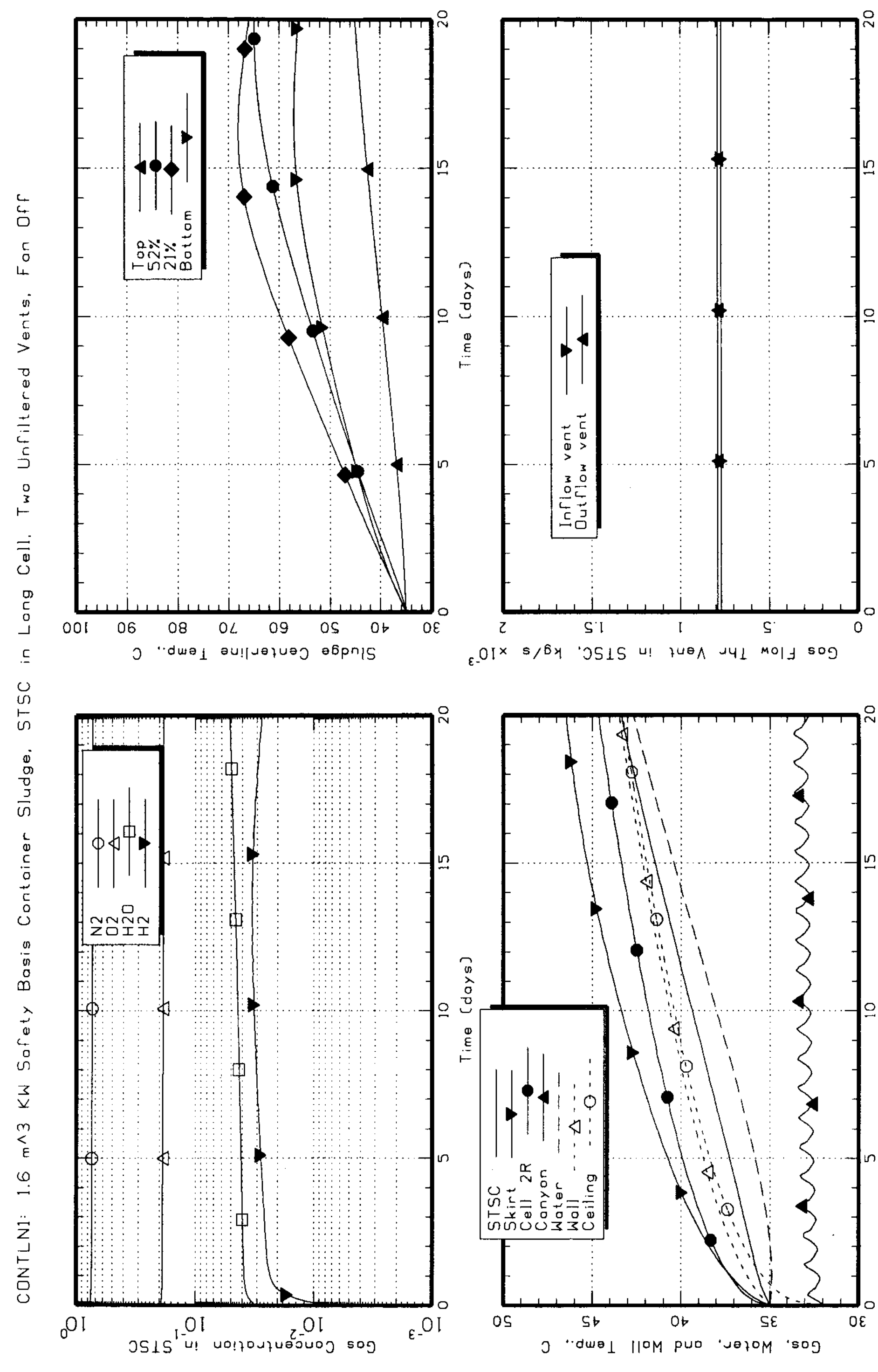


Figure 7-14: Case CONTLN1 Transient Results History (2 of 3)

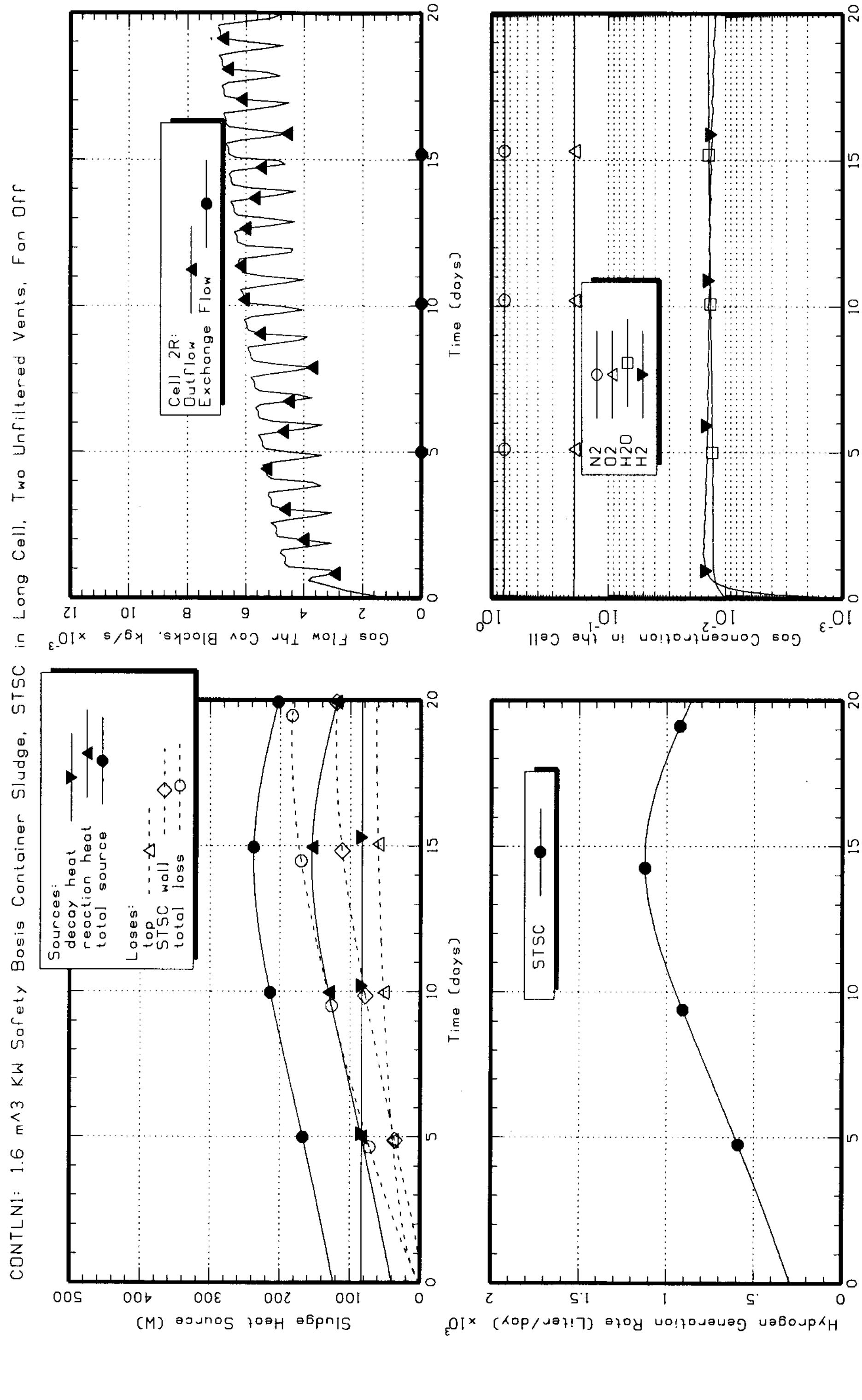


Figure 7-15: Case CONTLN1 Transient Results History (3 of 3)

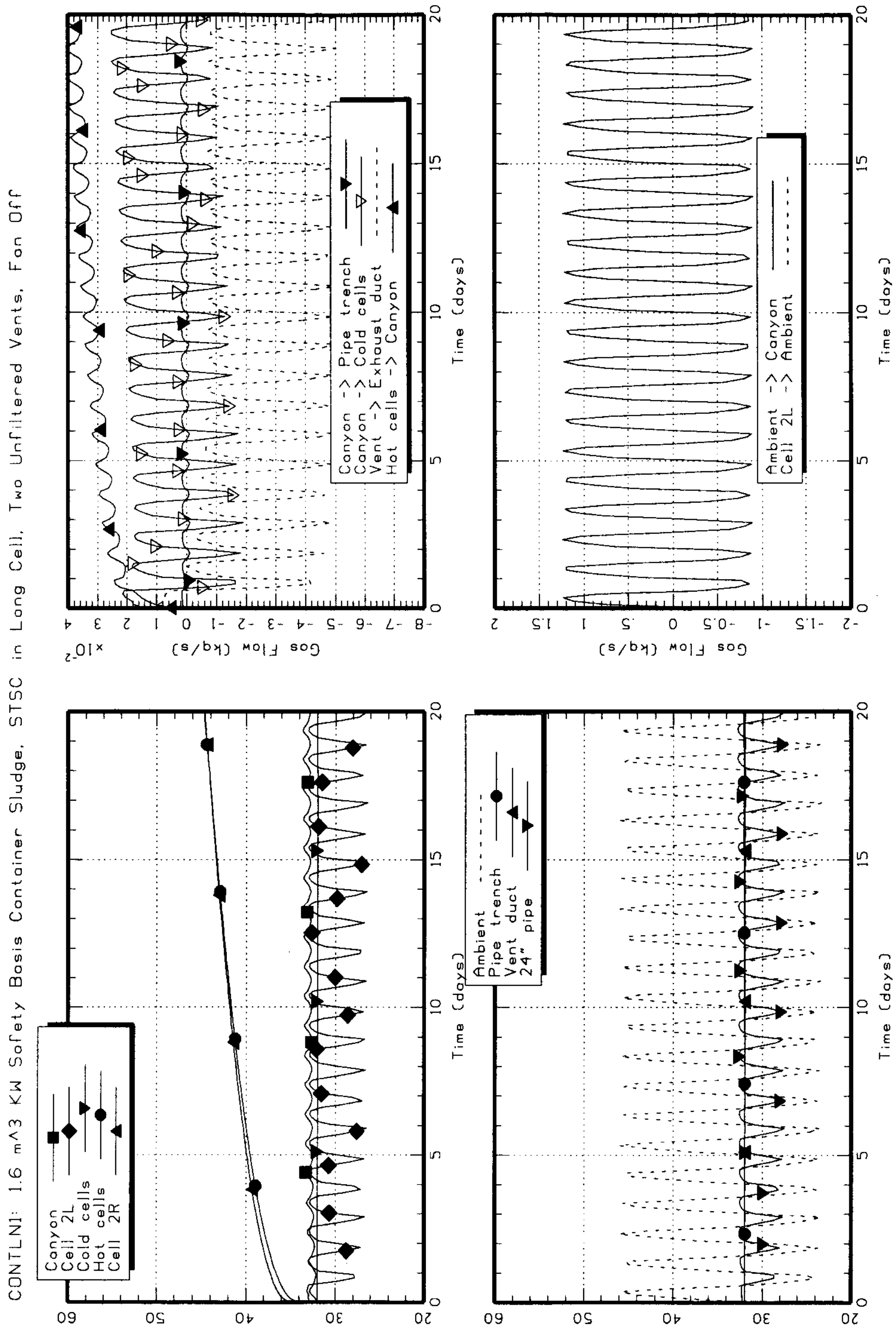


Figure 7-16: Case SETTRF1 Transient Results History (1 of 3)

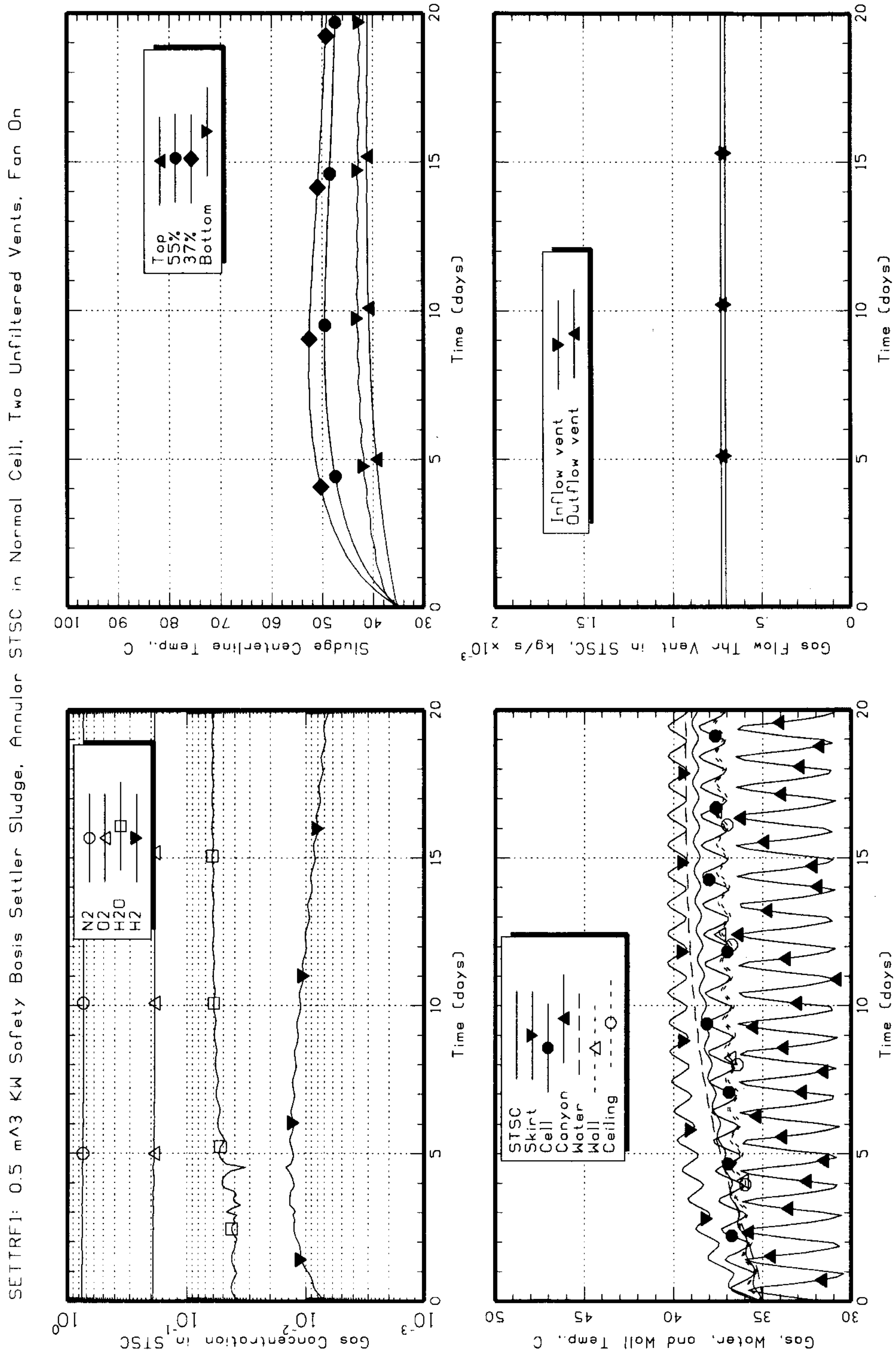


Figure 7-17: Case SETTRF1 Transient Results History (2 of 3)

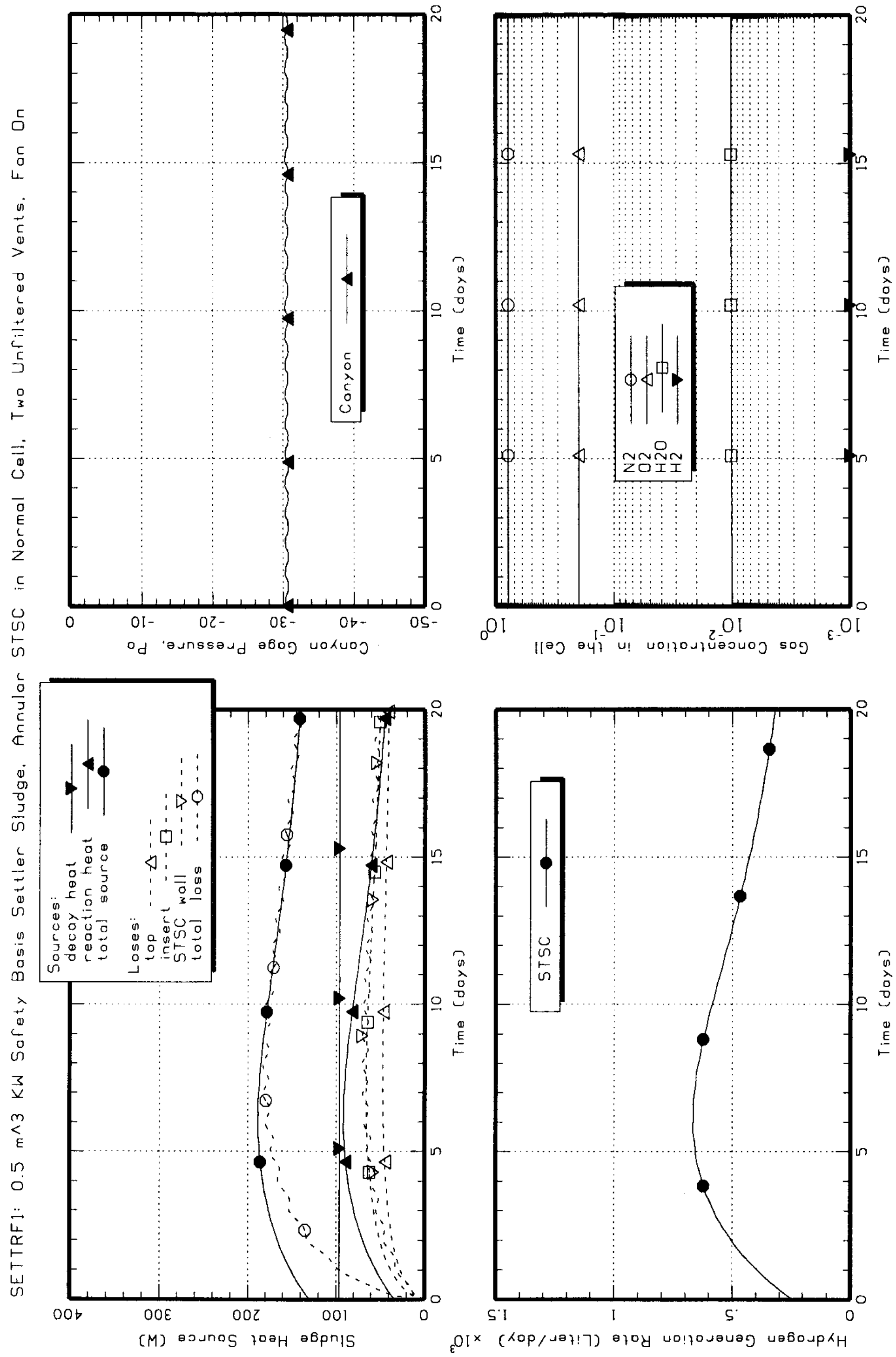


Figure 7-18: Case SETTRF1 Transient Results History (3 of 3)

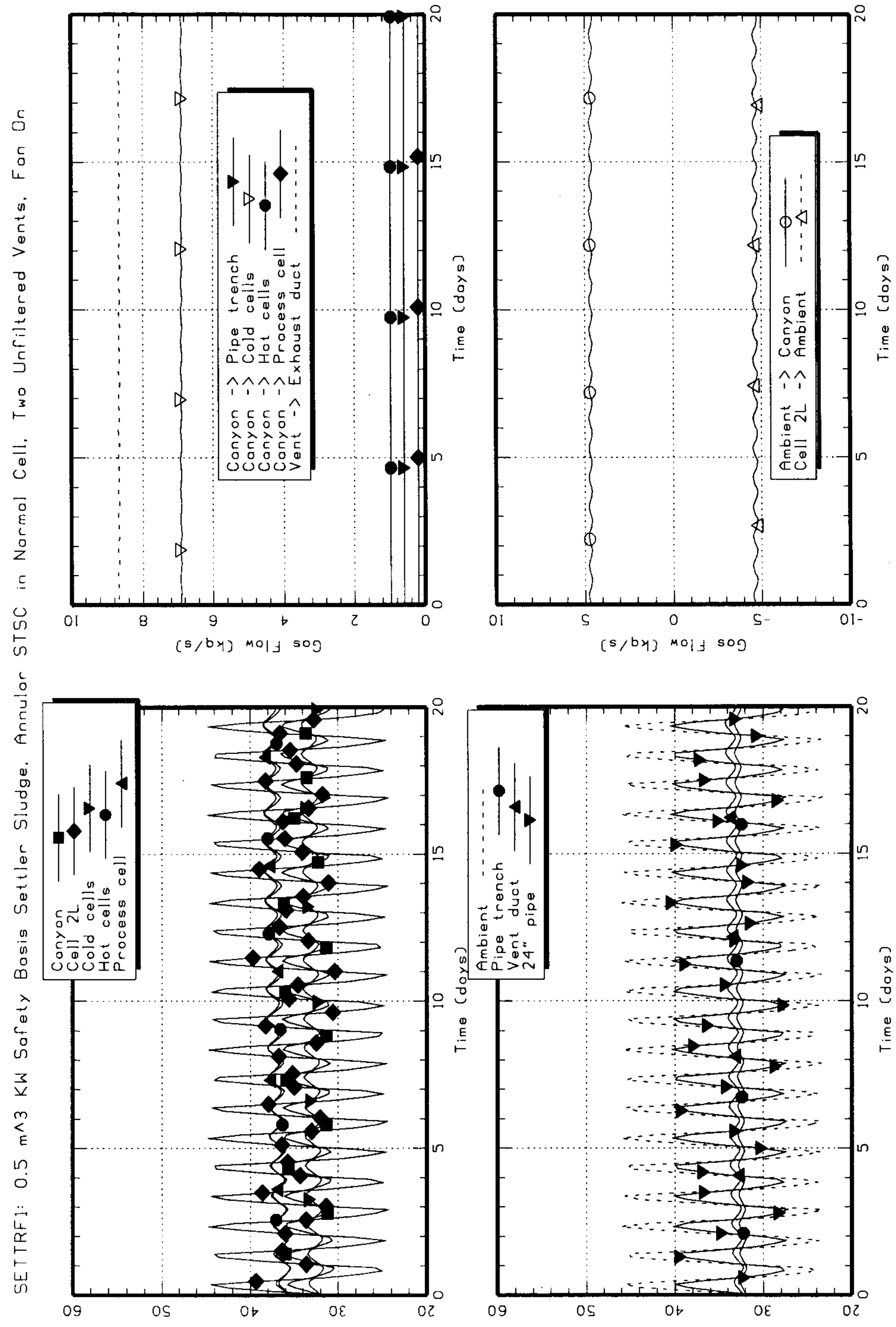


Figure 7-19: Case SETTLF1 Transient Results History (1 of 3)

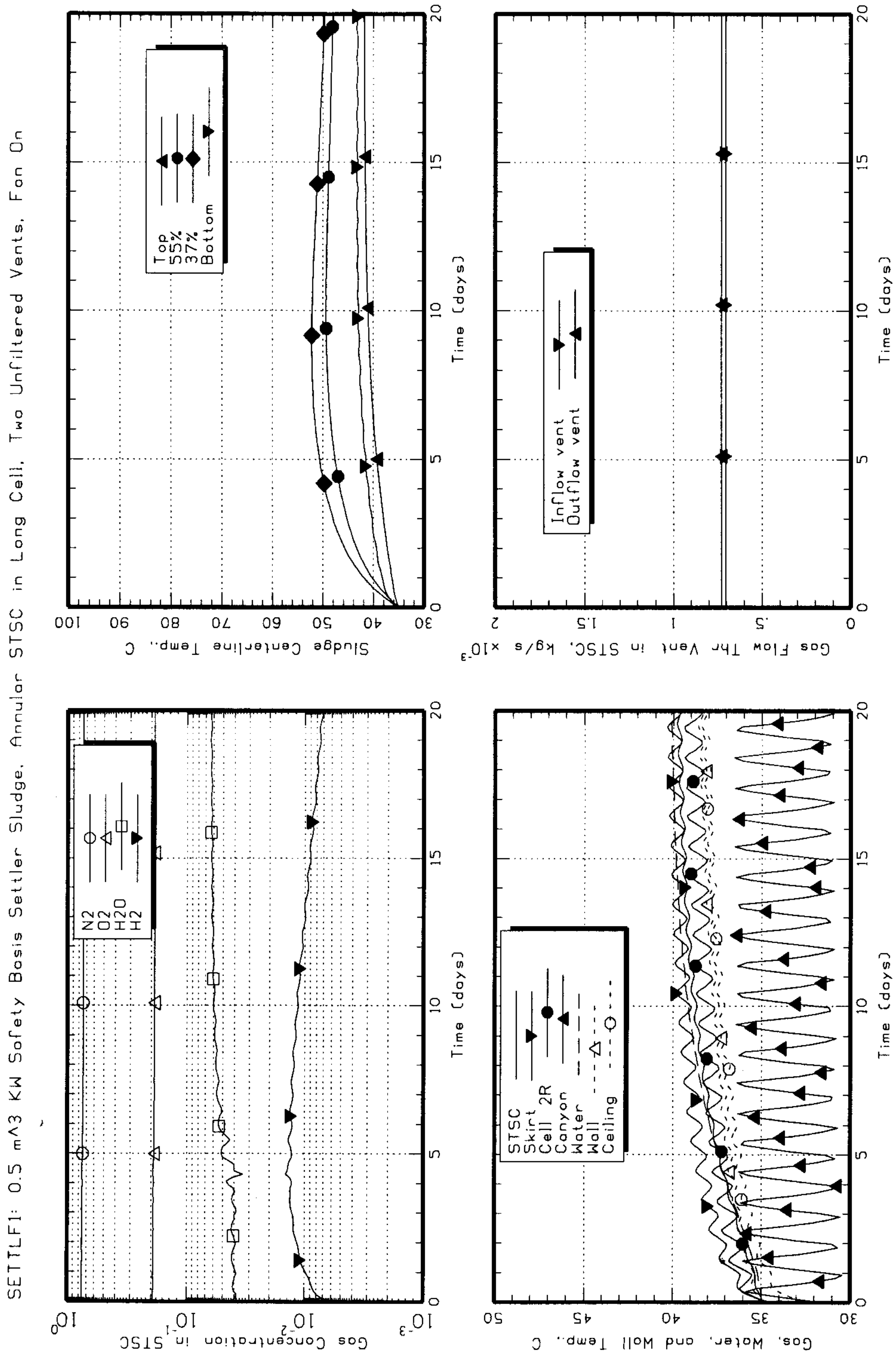


Figure 7-20: Case SETTLF1 Transient Results History (2 of 3)

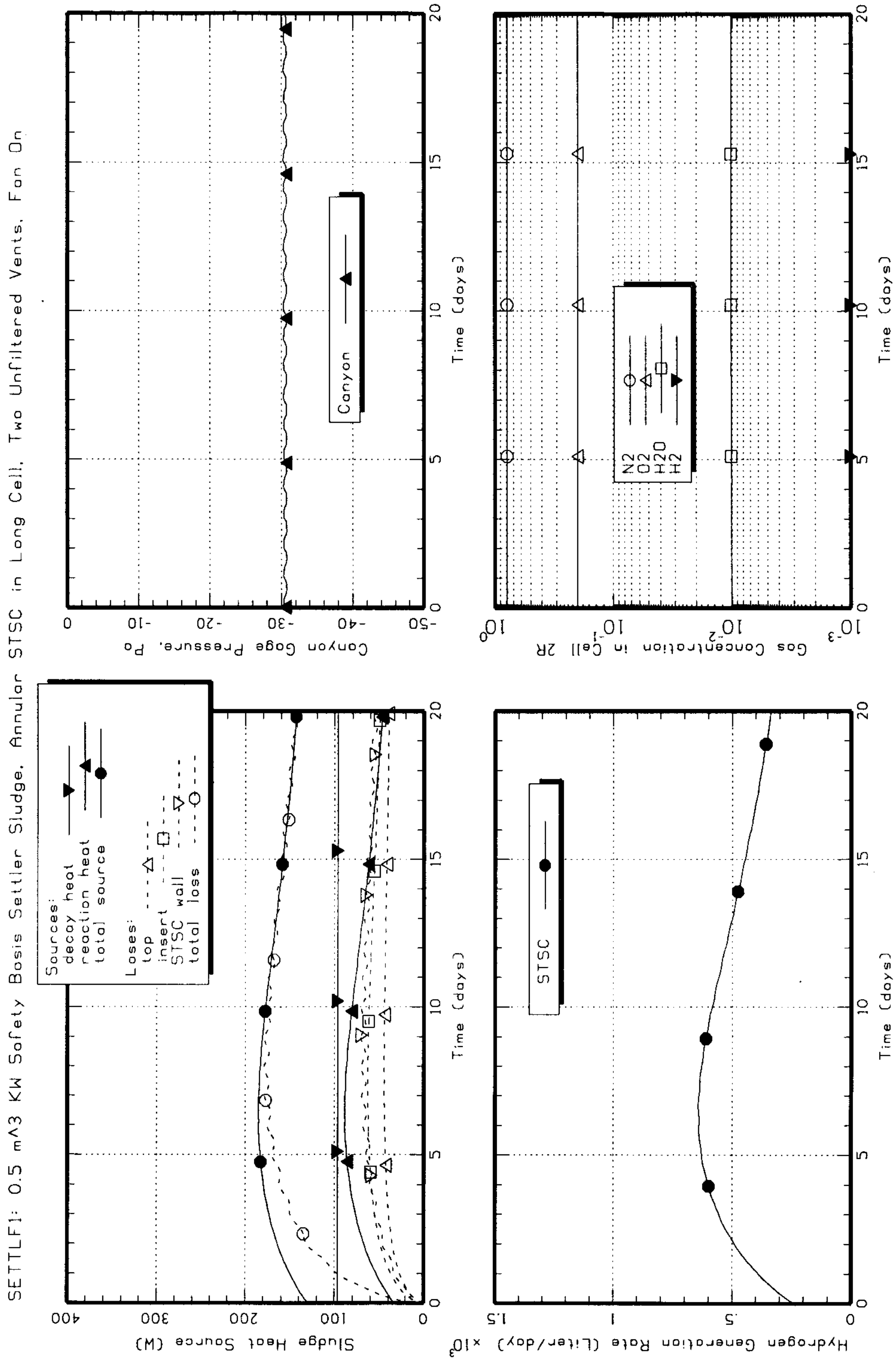


Figure 7-21: Case SETTLF1 Transient Results History (3 of 3)

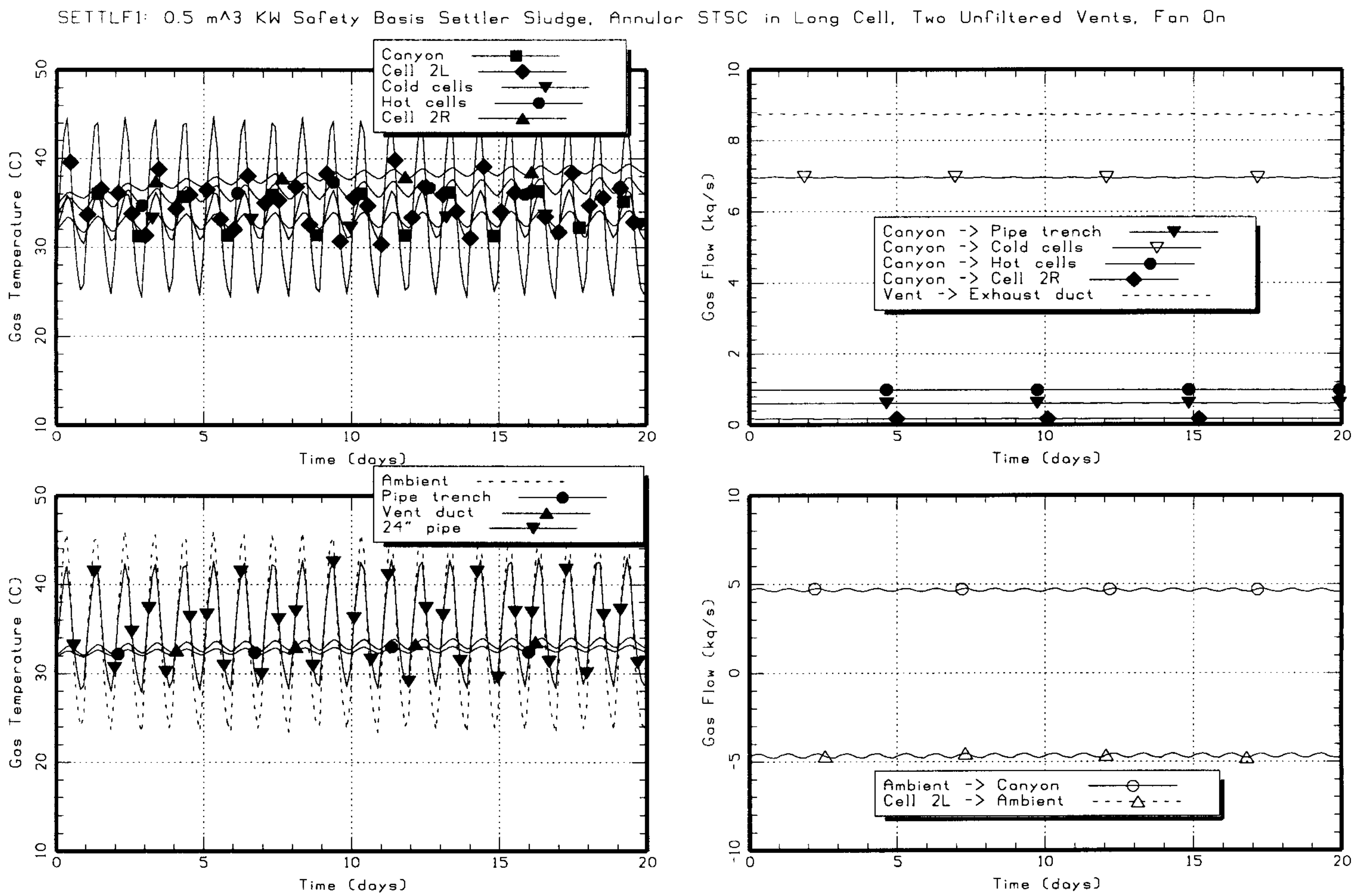


Figure 7-22: Case SETTRN1 Transient Results History (1 of 3)

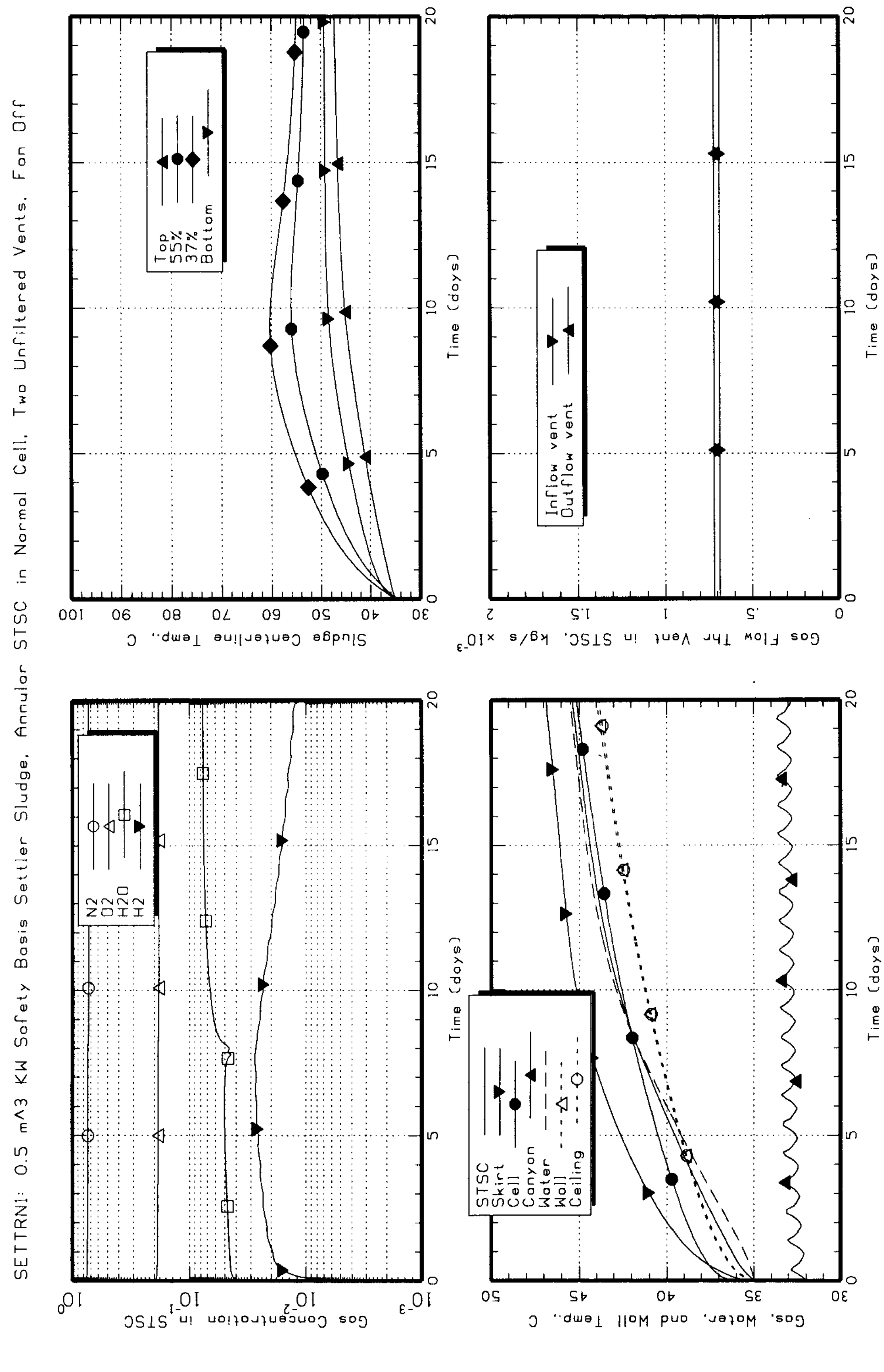


Figure 7-23: Case SETTRN1 Transient Results History (2 of 3)

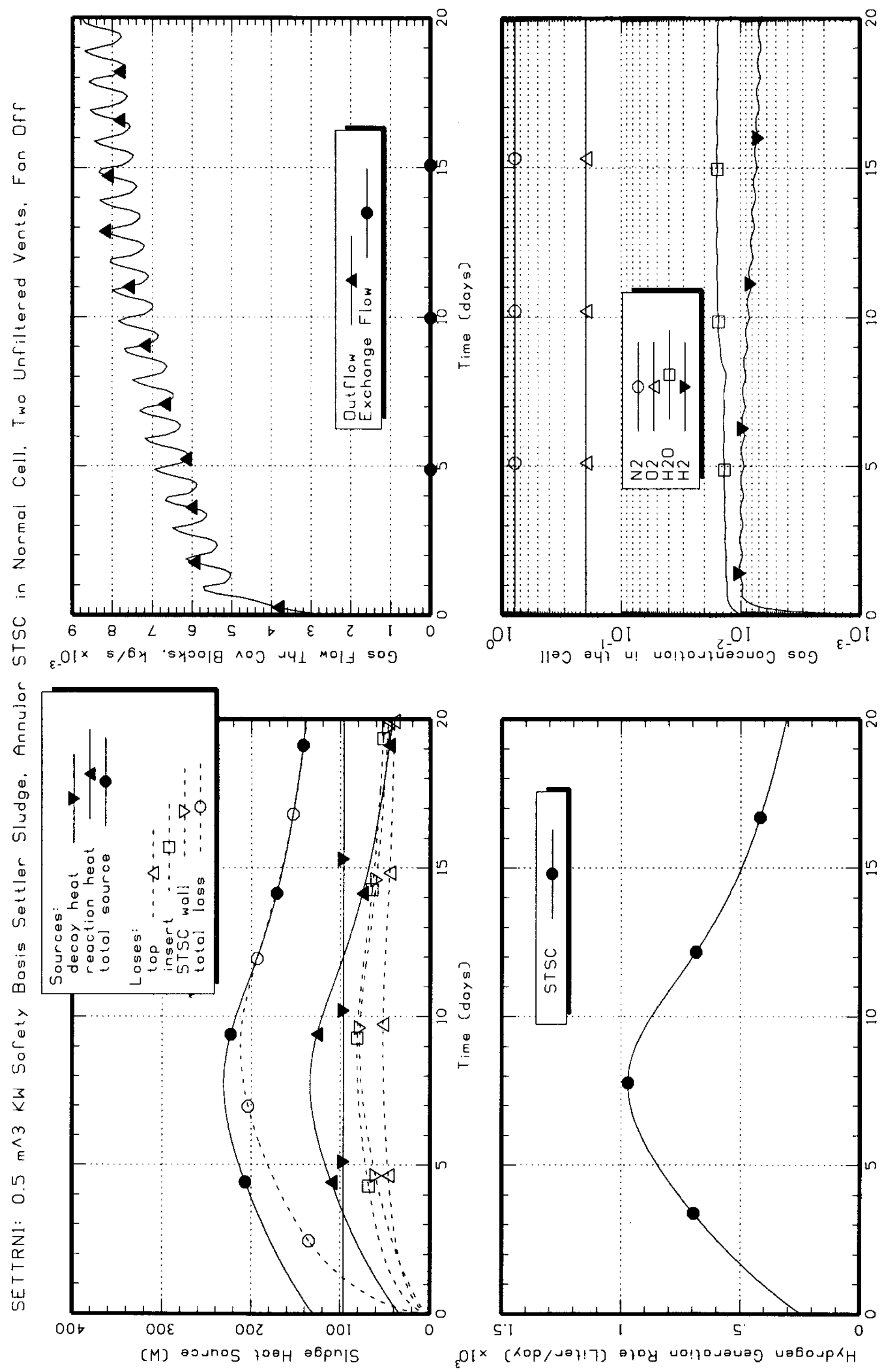


Figure 7-24: Case SETTRN1 Transient Results History (3 of 3)

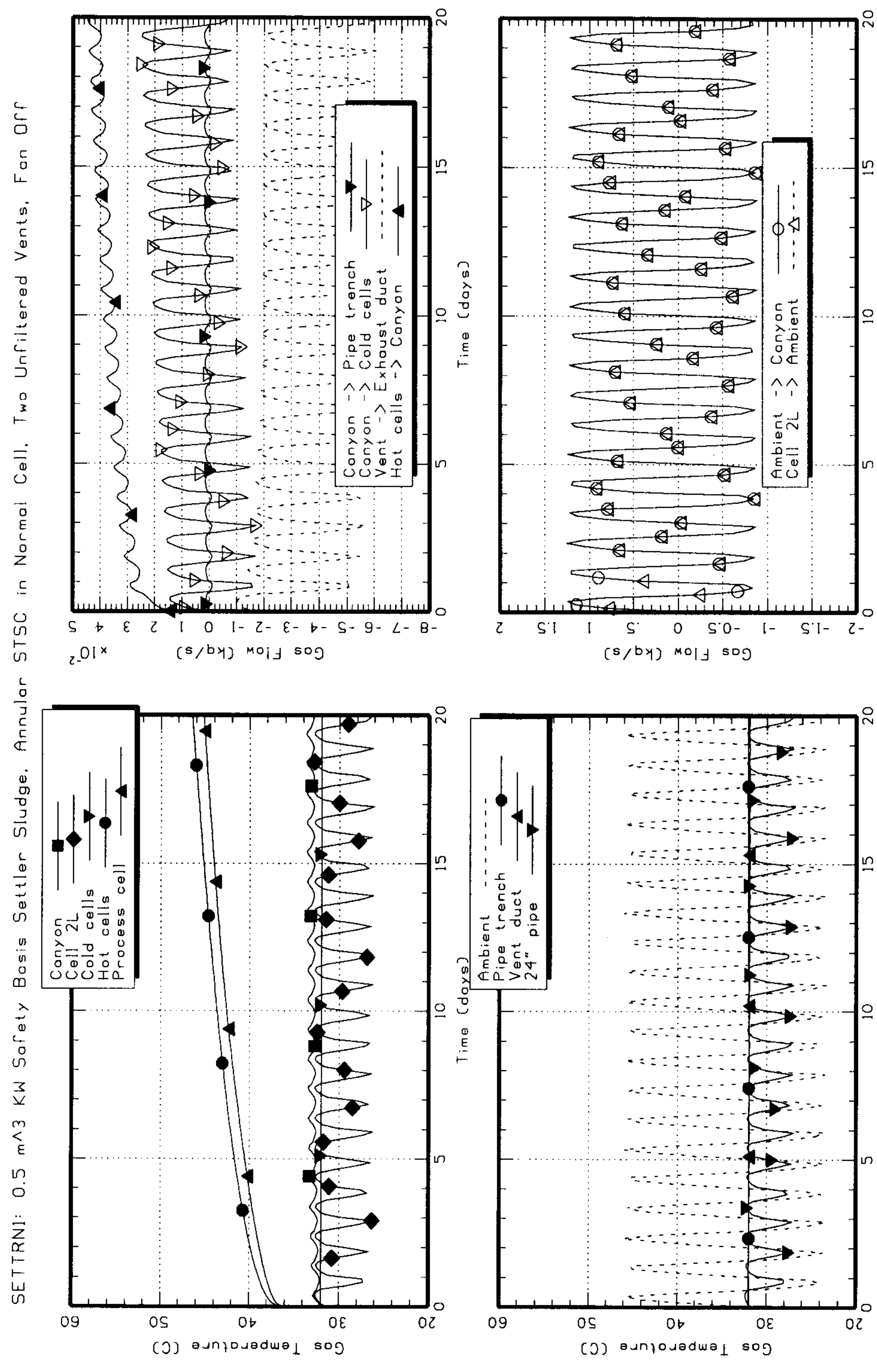


Figure 7-25: Case SETTLN1 Transient Results History (1 of 3)

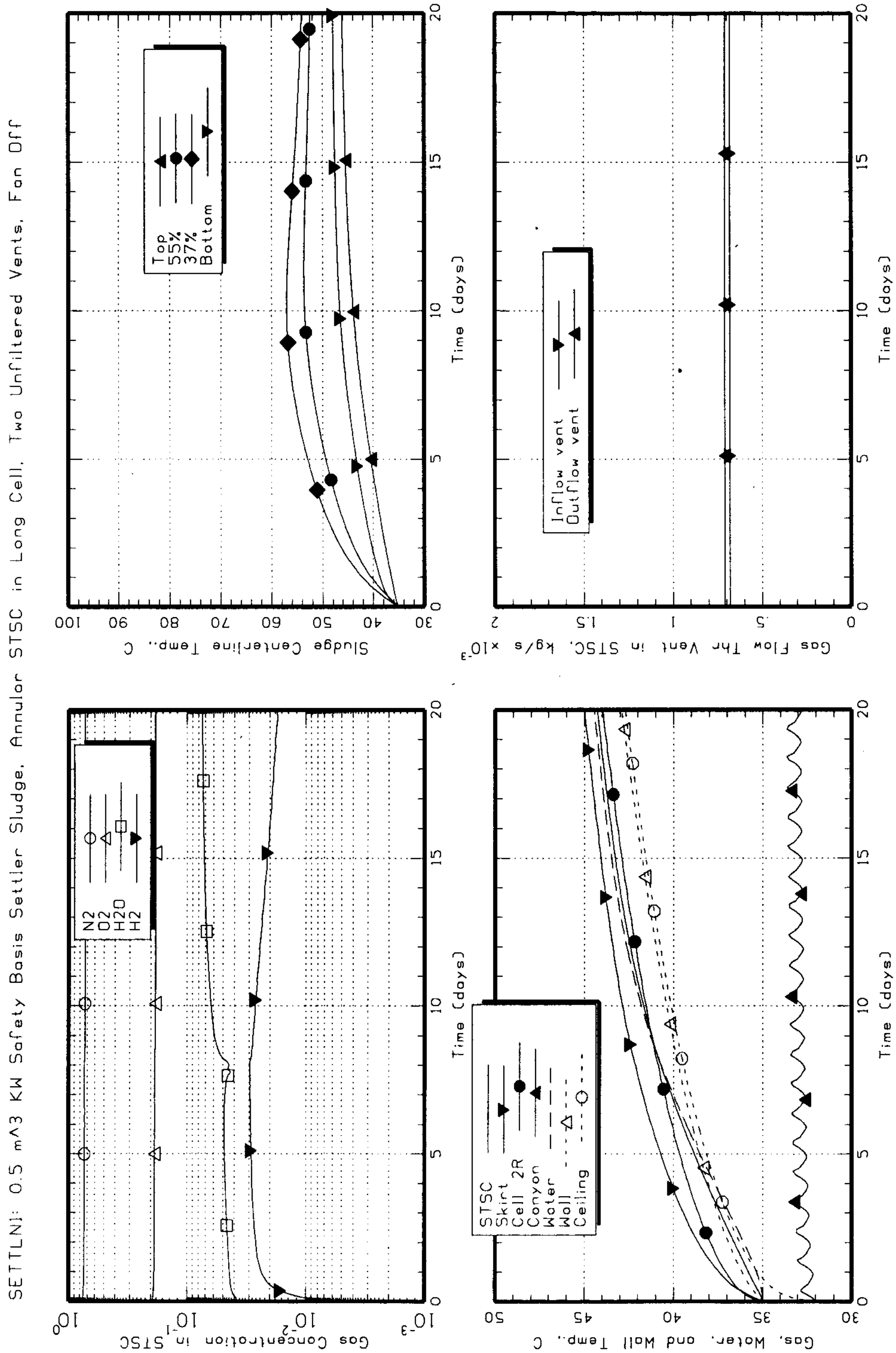


Figure 7-26: Case SETTLN1 Transient Results History (2 of 3)

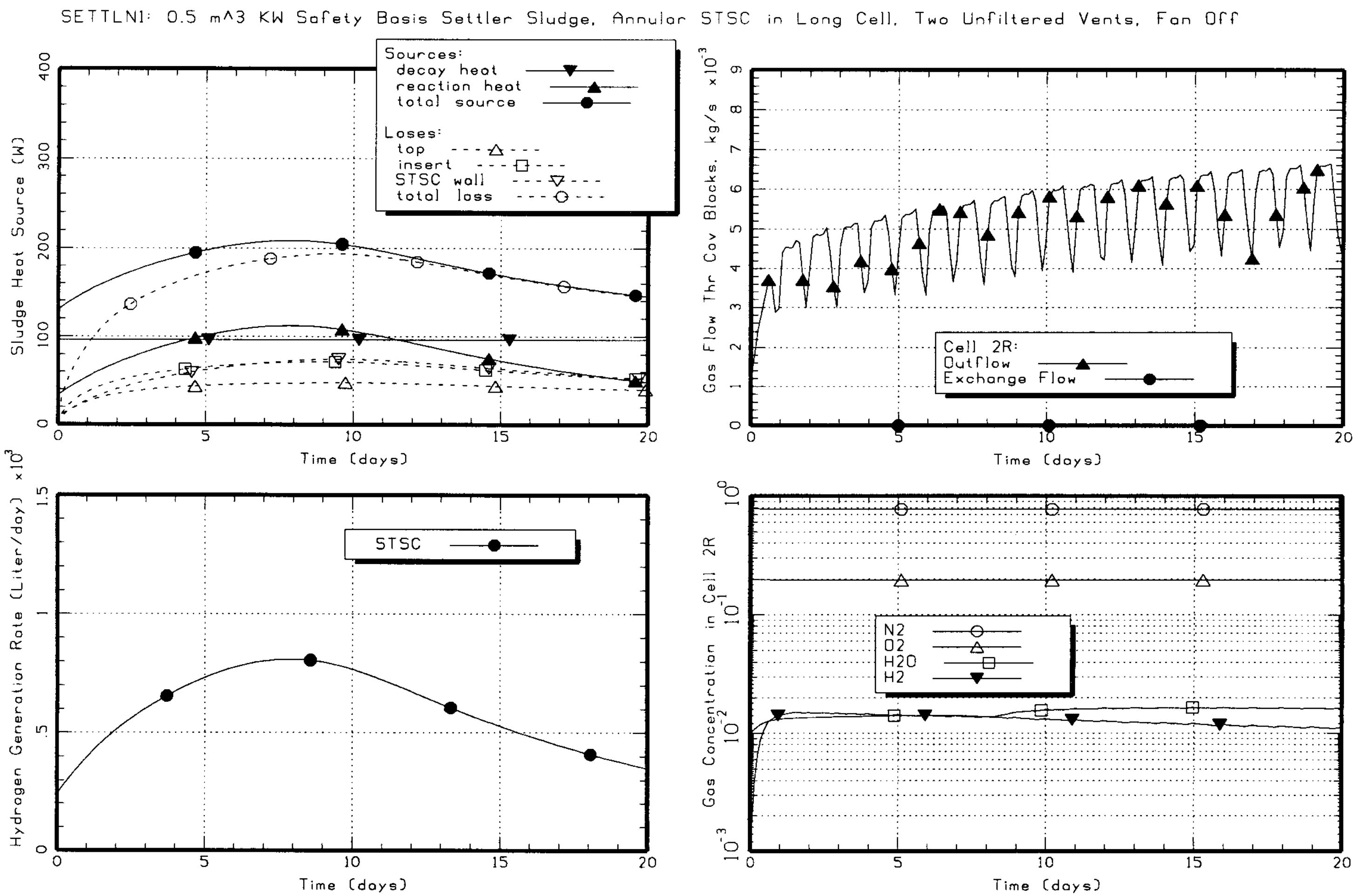
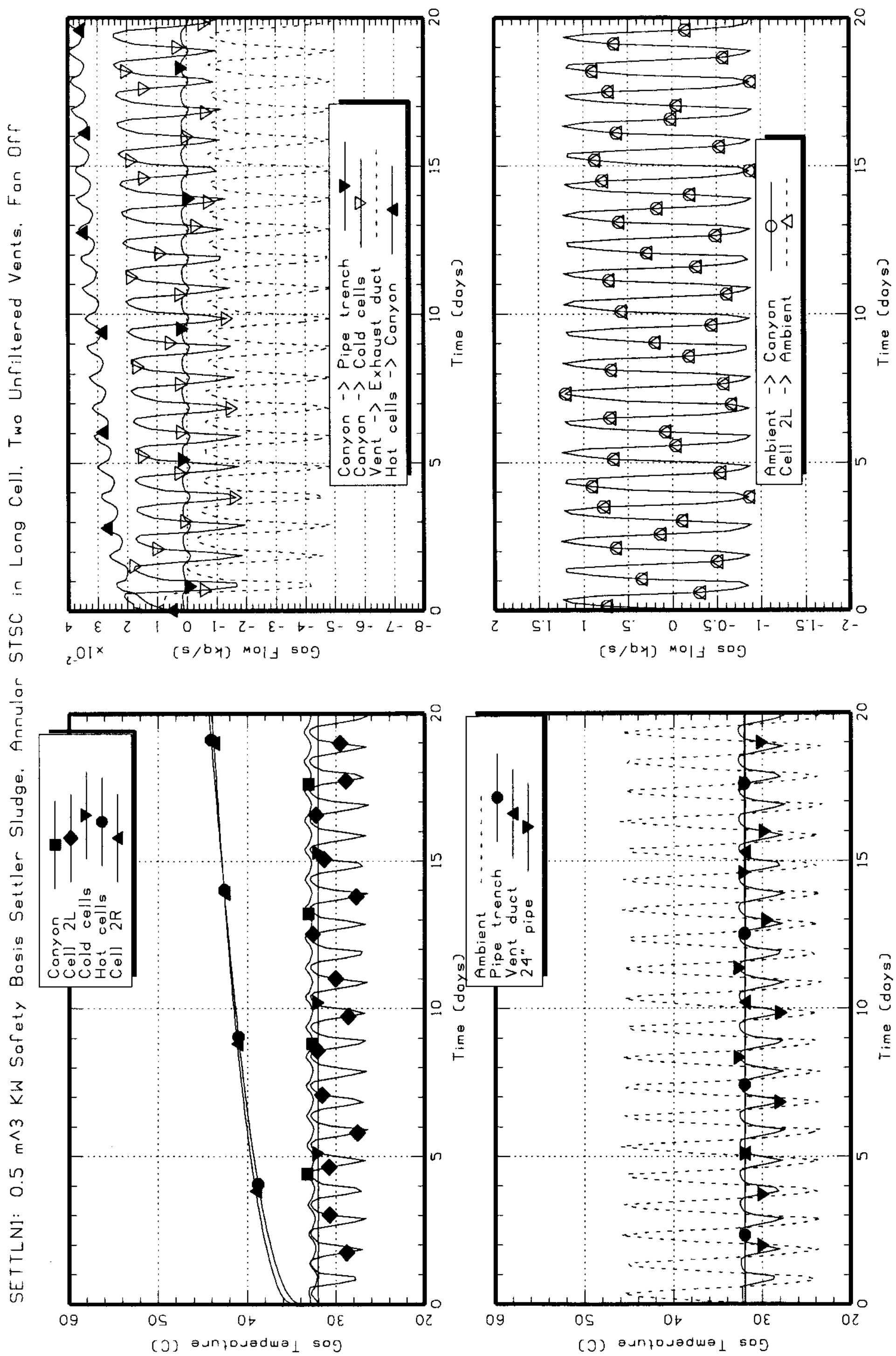


Figure 7-27: Case SETTLN1 Transient Results History (3 of 3)



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APPENDIX A: FATE™ INPUT values

This Appendix presents the derivation of selected input values to FATE for analysis of an STSC at T Plant. Parameters considered are:

1. Region volume and elevation inputs,
2. Junction inputs for STSC vent paths to the cell,
3. Junction inputs for cell cover blocks,
4. Heat sink inputs for cell heat conductors,
5. Heat sink inputs for sludge and STSC wall conductors,
6. Heat and hydrogen sources, and
7. Sludge radiolysis inputs.

A.1 Region Volume and Elevation Inputs

Typical cell dimensions are 13 ft (3.96 m) wide, 17 ft 8 in long (5.38 m), and 22 ft (6.71 m) deep. The free volume in the normal cell, represented by Region 2 in the FATE model, is obtained by subtracting the approximate volume of six STSCs and 1.0 m^3 for other structures in the cell. That is, for the normal cell, the region volume is given by $3.9624 \times 5.3848 \times 6.7056 - 6 \times 2.5941 \times \pi (1.4986)^2/4 - 1.0 = 114.63\ m^3$. Without STSCs and internal structures, the cell volume is 143.08 m^3.

Cell 2R differs only in its length with respect to the other cells, 27 ft 6 in (8.38 m) instead of 17 ft 8 in (5.38 m). The free volume I the long cell is obtained by subtracting the approximate volume of eight STSCs and 1.0 m^3 for other structures in the cell. That is, for the long cell, the region volume is given by $3.9624 \times 8.3820 \times 6.7056 - 8 \times 2.5941 \times \pi (1.4986)^2/4 - 1.0 = 185.11\ m^3$. Without STSCs and internal structures, the volume of cell 2R is 222.71 m^3.

Since the cell floor elevation is defined with respect to the bottom of the sludge, and the drip pan is located 38 in (0.9652 m) off the floor, the region floor elevation is given by $-0.9652 - 0.0254 = -0.9906$ m. Note that there is a 0.5 in (0.0127 m) STSC bottom wall thickness and another 0.5 in (0.0127 m) gap between the STSC bottom and the drip pan.

The height of the cell is 22 ft (6.7056 m).

The canyon is modeled as a very large volume to which the cell exchange air through the gap in concrete cover blocks. The floor elevation of the canyon volume is 28 ft (8.5344 m) above the cell floor, or $-0.9906 + 8.5344 = 7.5438$ m. Table A-1 summarizes the key region inputs for the cell and canyon volume.

Table A-1: Region Inputs for Cell Volumes

FATE Inputs	Standard Cell	Cold Cells	Hot Cells	Cell 2L	Cell 2R
Region Index	6	7	14	12	11
VOLUME	143.08 m^3 (114.63 m^3 with 6 STSCs & internals)	4435.48 m^3	458.52 m^3	251.39 m^3	222.71 m^3 (185.11 m^3 with 8 STSCs & internals)
ELEVATION	-0.9906 m	-0.9906 m	-0.9906 m	-1.8542 m	-0.9906 m
ZTOP	6.7056 m	6.7056 m	6.7056 m	7.5692 m	6.7056 m

Table A-2: Region Inputs for Other Volumes

FATE Inputs	Vent Duct	Pipe Trench	Canyon	24" Pipe	Exhaust Duct
Region Index	8	9	10	13	16
VOLUME	2023.0 m^3	951.45 m^3	40818 m^3	2.9357 m^3	115 m^3
ELEVATION	-0.9906 m	4.3434 m	7.5438 m	1.7526 m	-0.9906 m
ZTOP	6.7056 m	1.83 m	14.9352 m	0.6096 m	2.1336 m

A.2 Junction Inputs for STSC Vent Paths

One 2 in (0.0508 m) inlet vent and one 4 in (0.1016 m) outlet vent with 2 ft (0.6096 m) chimney in the STSC are modeled. Both vents have no filter, flow restriction, or bend. A discharge coefficient of 0.6 is assumed, which corresponds to a FATE loss coefficient CJN of $1/0.6^2 = 2.8$. Pertinent junction inputs for STSC vent paths to the cell are summarized in Table A-3.

Table A-3: Junction Inputs for STSC Vent Paths to the Cell

FATE Inputs	Junction	
	Inlet Vent	Outlet Vent
Junction Index	1	5
IR1, upstream node index	2	1
IR2, downstream node index	6 for settler sludge 1 for container sludge	2
OHORIZ, orientation = 0, vertical flow = 1, horizontal flow	0	0
AJN, flow area	2.03E-3	8.11E-3
Z1JN, inlet height from floor	3.8148	2.1732 for settler sludge 1.5929 for container sludge
Z2JN, outlet height from floor	2.6035 for settler sludge 1.5929 for container sludge	4.4244
CJN, loss coefficient	2.8	2.8
FGAS1JN, fraction of junction length occupied by donor gas	1.0	1.0

A.3 Junction Inputs for Cell Cover Blocks

The worst case gap widths for cell 3L cover blocks shown in Figure A-1 (HNF-12563, Rev. 2) are modeled using two junctions, one for upward and one for downward flow. Half the gap area is assumed to participate in upward flow and the other half in downward flow. In (HNF-12563, Rev. 2) the FATE input KFILTER, which characterizes the gap resistance by the relationship ΔP = KFILTER x Q, where Q is the volumetric flow rate, is determined for cell 3L cover blocks as following. The value of KFILTER for the three wider gaps is

$$KFILTER_3 = 786.8 \text{ Pa-sec/m}^3,$$

While for the two narrow gaps

$$KFILTER_2 = 2.673 \times 10^4 \text{ Pa-sec/m}^3.$$

The parallel combination of the two yields an effective value of KFILTER given by

$$KFILTER = (KFILTER_2 \times KFILTER_3) / (KFILTER_2 + KFILTER_3)$$

$$KFILTER = 764.3 \text{ Pa-sec/m}^3.$$

In the current analysis, the gaps are modeled using a single junction. The counter-current exchange of flow in the gaps is quantified by the exchange flowrate of the junction. Therefore, the KFILTER corresponding to the entire gap area is given by 764.3 / 2 = 382.15 Pa-sec/m^3.

For cell 2R, a long cell, there are two more cover blocks for a total of six cover blocks. Hence there are five wider gaps and three narrow gaps. Assuming the size of the wider gaps in cell 2R is same as that in cell 3L, the value of KFILTER for the five wider gaps can be easily obtained by

$KFILTER_5 = 3/5 \times KFILTER_3$

$KFILTER_5 = 472.1$ Pa-sec/m^3.

The parallel combination of the two yields an effective value of KFILTER given by

$KFILTER = (KFILTER_2 \times KFILTER_5) / (KFILTER_2 + KFILTER_5)$

KFILTER = 463.9 Pa-sec/m^3.

Again the KFILTER corresponding to the entire gap area is given by 463.9 / 2 = 231.95 Pa-sec/m^3.

Pertinent junction inputs for the cover block gaps are summarized in Table A-4.

Figure A-1: Worst Case Gap Widths for Cell 3L Cover Blocks.

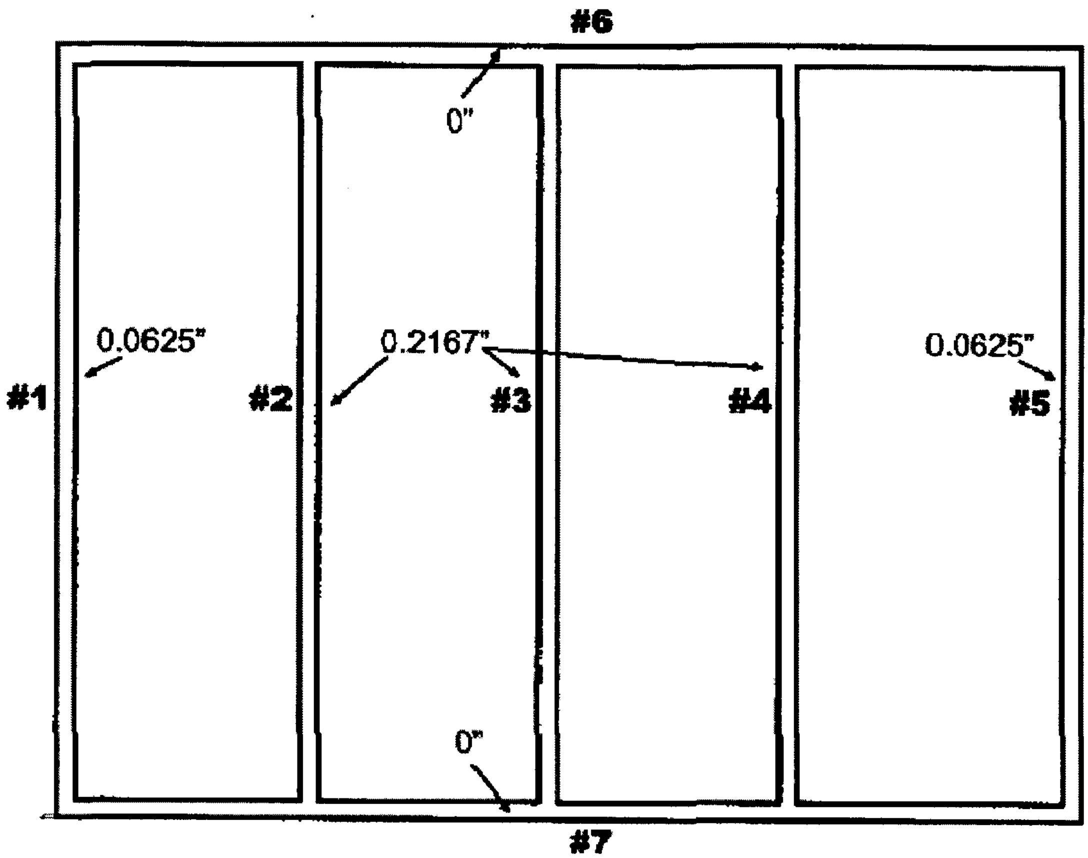


Table A-4: Junction Inputs for Cover Block Gaps

FATE Inputs	Junction	
	Normal Process Cell	Long Process Cell (2R)
Junction Index	11	17
IR1, upstream node index	6	11
IR2, downstream node index	10	10
OHORIZ, orientation = 0, horizontal flow = 1, vertical flow	1	1
AJN, flow area	1.0[1]	1.0[1]
Z1JN, inlet height from floor	0.0	0.0
Z2JN, outlet height from floor	6.7056	6.7056
CJN, loss coefficient	1.E-5	1.E-5
KFILTER	382.15	231.95
FGAS1JN, fraction of junction length occupied by donor gas	1.0	1.0

[1] For junctions with KFILTER > 0 the junction flow area does not affect the flow rate. However, a non-zero junction flow area has to be specified to make it an active junction.

A.4 Heat Sink Inputs for Cell Heat Conductors

The two long side walls are represented by a heat conductor and the two short side walls are represented by a second heat conductor. One side of each heat conductor faces the cell and the other side is insulated. The characteristic height of each heat conductor for natural convection heat transfer is 6.7056 m.

The cover block is represented as a 6 ft (1.8288 m) thick concrete heat conductor. Its one-sided area is given by 5.3848 x 3.9624 = 21.337 m^2 for normal cell and 8.3820 x 3.9624 = 33.21 m^2 for long cell. The characteristic height of the heat conductor for natural convection heat transfer is 3.9624 m. Note that the cell concrete floor is not represented since it is normally cooler than the cell gas and very little heat transfer is expected between the two. The heat sink inputs for cell heat conductors are summarized in Table A-5.

Table A-5: Heat Sink Inputs for Normal Cell Heat Conductors

FATE Inputs	Heat Sink		
	Long Side Wall	Short Side Wall	Cover Block
Heat Sink Index	101	102	103
IORIHS, orientation = 0 for vertical = 1 for horizontal	0	0	1
XRO, thickness	1.067	1.372	1.829
AHS, one-sided area	72.217	53.141	21.337
IREGI, region inner surface faces	6	6	10
IREGO, region outer surface faces	0	0	6
XLHS, characteristic height	6.7056	6.7056	3.9624
ZTHS, top elevation	5.7150	5.7150	7.5438
ZBHS, bottom elevation	-0.9906	-0.9906	5.7150
IMATHS, material type[1]	3	3	3

[1] Material type 3 represents concrete with density, thermal conductivity, specific heat, and emissivity of 1850 kg/m^3, 0.6 W/m/K, 960 J/kg/K, and 0.75, respectively.

Table A-6: Heat Sink Inputs for Long Cell Heat Conductors

FATE Inputs	Heat Sink		
	Long Side Wall	Short Side Wall	Cover Block
Heat Sink Index	111	112	113
IORIHS, orientation = 0 for vertical = 1 for horizontal	0	0	1
XRO, thickness	1.067	1.372	1.829
AHS, one-sided area	56.206[2]	53.141	33.21
IREGI, region inner surface faces	11	11	10
IREGO, region outer surface faces	0	0	11
XLHS, characteristic height	6.7056	6.7056	3.9624
ZTHS, top elevation	5.7150	5.7150	7.5438
ZBHS, bottom elevation	-0.9906	-0.9906	5.7150
IMATHS, material type[1]	3	3	3

[1] Material type 3 represents concrete with density, thermal conductivity, specific heat, and emissivity of 1850 kg/m^3, 0.6 W/m/K, 960 J/kg/K, and 0.75, respectively.

[2] Represents only one long side. The other long side is represented by heat sink 114 which is between Cell 2R and Cell 2L.

A.5 Heat Sink Inputs for Sludge

The sludge in the elliptical bottom head of STSC is axially nodalized using 10 short annular disks as shown in Figure 6-1. Table A-7 summarizes the dimensions of the sludge nodes in the bottom head. There are two rows given per heat sink, and the meaning of each row and column is described next.

Table A-7: Sludge Node Dimensions in Elliptical Bottom Head

	Y	RI	VI	SI	RO	VO	SO	VO-VI
	0.3683	0.30480	0.07783		0.73660	0.41853		
LAYER-10			0.01205	0.07909		0.07011	0.19175	0.05806
	0.3270	0.30480	0.06578		0.73195	0.34842		
LAYER-9			0.01202	0.07890		0.06817	0.19830	0.05615
	0.2858	0.30480	0.05376		0.71788	0.28025		
LAYER-8			0.01197	0.07852		0.06435	0.21056	0.05238
	0.2448	0.30480	0.04179		0.69395	0.21590		
LAYER-7			0.01214	0.07967		0.05995	0.23238	0.04781
	0.2032	0.30480	0.02965		0.65844	0.15595		
LAYER-6			0.01489	0.11669		0.06595	0.33085	0.05106
	0.1500	0.26766	0.01476		0.59326	0.09000		
LAYER-5			0.01162	0.10230		0.04791	0.35101	0.03629
	0.1000	0.22428	0.00314		0.50462	0.04209		
LAYER-4			0.00208	0.07886		0.01782	0.19157	0.01574
	0.0750	0.16481	0.00106		0.44551	0.02427		
LAYER-3			0.00106	0.08625		0.01288	0.19590	0.01182
	0.0508	0.0000	0.00000		0.37330	0.01139		
LAYER-2			0.00000	0.00000		0.00847	0.21692	0.00847
	0.0254	0.0000	0.00000		0.26881	0.00292		
LAYER-1			0.00000	0.00000		0.00292	0.22802	0.00292
	0.0	0.0000	0.00000		0.00000	0.00000		

Each column in the table is defined either at the node center or at node boundaries, and is determined as follows.

Y – axial node boundary elevation, m.

RI – inner radius at axial node boundaries, m. The inner radius of the sludge is determined by

$$RI = R_{insert}\sqrt{1-\frac{\left(Y-0.0508-\frac{R_{insert}}{2}\right)^2}{\left(\frac{R_{insert}}{2}\right)^2}}\text{, Y} \geq 0.0508$$

0.0, Y < 0.0508

where R_{insert} is the major radius of the insert (0.3048 m).

VI – cumulative volume of the elliptical insert at node boundaries, m. VI is determined by

$$VI = 4\,\pi\left(\frac{R_{insert}}{2}\left(Y-0.0508\right)^2-\frac{\left(Y-0.0508\right)^3}{3}\right),\ \mathrm{Y} \geq 0.0508$$

0.0, Y < 0.0508

VI is determined at axial node boundaries. Then, the difference between node boundary values is taken as the node value in Table A-7. This quantity is used later to determine the sludge volume in the annular disk.

SI – inner surface area of the sludge node in contact with insert, m. SI is estimated by

$$SI = 2\,\pi\left(\frac{RI_{top}+RI_{bottom}}{2}\right)\sqrt{\left(Y_{top}-Y_{bottom}\right)^2+\left(RI_{top}-RI_{bottom}\right)^2}$$

where the subscripts "*top*" and "*bottom*" refer to the node top and bottom boundary values.

RO – outer radius at axial node boundaries, m. The outer radius of the sludge is determined by

$$RO = R_{STSC}\sqrt{1-\frac{\left(Y-\frac{R_{STSC}}{2}\right)^2}{\left(\frac{R_{STSC}}{2}\right)^2}}$$

where R_{STSC} is the radius of the STSC (0.73428 m).

VO – cumulative volume of the elliptical STSC at node boundaries, m. VO is determined by

$$VO = 4\,\pi\left(\frac{R_{STSC}}{2}Y^2-\frac{Y^3}{3}\right)$$

VO is determined at axial node boundaries. The difference between node boundary values is taken as the node value in Table A-7. This quantity is used later to determine the sludge volume in the annular disk.

SO – outer surface area of sludge node in contact with STSC, m. SO is estimated by

$$SO = 2\,\pi\left(\frac{RO_{top}+RO_{bottom}}{2}\right)\sqrt{\left(Y_{top}-Y_{bottom}\right)^2+\left(RO_{top}-RO_{bottom}\right)^2}$$

where the subscripts "*top*" and "*bottom*" refer to the node top and bottom boundary values.

VO-VI - the difference between nodal-VO and nodal-VI gives the annular disk sludge volume.

The insert wall, sludge, and STSC heat conductors at each row in the STSC bottom head are normally treated as an annular composite heat sink. To consider the curvature of surface, following approximation are used for FATE sludge heat conductor inputs.

XRI, inner radius,	$(RI_{top} + RI_{bottom}) / 2$
XRO, outer radius,	$(RO_{top} + RO_{bottom}) / 2$
XZHS, conduction distance,	$(Y_{top} + Y_{bottom}) / 2$
AHS, one-sided area,	$\pi \times (XRI + XRO) \times XZHS$
ASHSI, inner surface area,	SI
ASHSO, outer surface area,	SO
VOLHS, volume,	VO-VI

The sludge heat sink conducts heat to the adjacent insert and STSC walls. Therefore, AHS of the insert and STSC walls are set to ASHSI and ASHSO of the sludge, respectively. Also, the conduction distance XZHS of the insert and STSC walls are set to $\sqrt{\left(Y_{top} - Y_{bottom}\right)^2 + \left(RI_{top} - RI_{bottom}\right)^2}$ and $\sqrt{\left(Y_{top} - Y_{bottom}\right)^2 + \left(RO_{top} - RO_{bottom}\right)^2}$, respectively.

The STSC bottom head is cooled by the air in the support skirt enclosure. The STSC bottom head surface is vertical at the top but progressively becomes flat near the bottom. Therefore, the orientation of the STSC wall flag, IORIHS, is set to "0" for the top three layers but "1" for the bottom seven layers. In FATE, heat transfer due to laminar boundary layer underside of a hot plate is modeled.

For the third row, the insert wall is not modeled. Instead, the sludge is exposed to water on the top using the "fin" feature of FATE. The exposed portion of the third row corresponds to RI_{top} of the sludge heat conductor, 0.16481 m. The exposed area corresponds to SI, 0.08625 m^2.

The resistance in the 0.25 inch insert wall is considered by increasing the conduction distance in the sludge by the equivalent distance. That is,

$$\frac{\left(\dfrac{XZHS_{effective}}{2}\right)}{k_{sludge}} = \frac{\left(\dfrac{XZHS}{2}\right)}{k_{sludge}} + \frac{X_{insert}}{k_{ss}}$$

Where k_{sludge} is the thermal conductivity of sludge (0.7 W m^{-1} K^{-1}), k_{ss} is the thermal conductivity of stainless steel (16 W m^{-1} K^{-1}), X_{insert} is the insert wall thickness (0.00635 m), $XZHS$ is the conduction distance, or height, of the sludge node (0.0242 m), and $XZHS_{effective}$ is the effective conduction distance to be determined. The above equation can be easily solved to yield $XZHS_{effective} = 0.0248\, m$. Note that this estimate is conservative because the actual conduction distance in the third row is smaller than the node height.

Similarly, the STSC wall is not modeled for the first row. Instead, the sludge is exposed to air on the bottom. The exposed area corresponds to SO, 0.22802 m^2.
The resistance in the 0.5 inch STSC wall is considered by increasing the conduction distance in the sludge by the equivalent distance. That is,

$$\frac{\left(\frac{XZHS_{effective}}{2}\right)}{k_{sludge}} = \frac{\left(\frac{XZHS}{2}\right)}{k_{sludge}} + \frac{X_{STSC}}{k_{ss}}$$

Where k_{sludge} is the thermal conductivity of sludge (0.7 W m^{-1} K^{-1}), k_{ss} is the thermal conductivity of stainless steel (16 W m^{-1} K^{-1}), X_{STSC} is the STSC wall thickness (0.0127 m), $XZHS$ is the conduction distance of the sludge node (0.0254 m), and $XZHS_{effective}$ is the effective conduction distance to be determined. The above equation can be easily solved to yield $XZHS_{effective} = 0.0265\ m$.

A.6 Heat and Hydrogen Sources

Only one STSC is analyzed in detail within the process cell or the cell 2R. To simulate the other STSCs in the hot cells or the cell of interest, the decay power, peak reaction power, and peak hydrogen generation rate for a single STSC was used.

Decay power in one STSC loaded with container sludge is given by 1.6 m^3 * 590 Kg-U/m^3 * 0.08814 W/kg-U = 83.2W. Oxidation power of 116 W was estimated from a FATE run analyzing a container sludge STSC in conditions similar to the T-Plant model. Similarly, the peak hydrogen generation rate was found to be 838 l/day * 1/86400 day/s * 0.07598 kg/m**3 * 1/1000 m**3/l = 7.37E-7 kg/s. Similar estimates were made for settler sludge.

Table A-8: Heat and Hydrogen Generation of Typical STSCs

	Settler Sludge STSC	Container Sludge STSC
Decay Power [W]	96.5	83.2
Reaction Power [W]	96	116
H_2 Generation Rate [kg/s]	7.0E-7	7.37E-7

A.7 Sludge Radiolysis Inputs

The best available calculation for sludge radiolysis is contained in SNF-22059, Revision 0, Attachment 12. The rate of hydrogen production from radiolysis W_{H2}, kg/s, is

$$W_{H2} = CQ\left[f_{q\alpha}e_{\alpha}g_{\alpha} + f_{q\beta}e_{\beta}g_{\beta} + f_{q\gamma}e_{\gamma}g_{\gamma}\right]$$

where

C = Units conversion factor,

$$C = \frac{1}{100\ \text{eV}} \text{x} \frac{1\ \text{eV}}{1.602\text{x}10^{-19}\ \text{J}} \text{x} \frac{0.002\ \text{kg}}{6.02\text{x}10^{23}\ \text{molecules}} = 2.07\text{x}10^{-10}$$

Q = Decay power, W,

f_q = Fraction of decay power for the given radiation type,

e = Fraction of power absorbed by water for the given radiation type, and

g = g(H_2), molecules H_2 per 100 eV absorbed by water,

and alpha, beta, and gamma radiation are respectively considered. An average g value G may be defined for convenience,

$$G = f_{q\alpha}e_\alpha g_\alpha + f_{q\beta}e_\beta g_\beta + f_{q\gamma}e_\gamma g_\gamma$$

which results in a simplified version of the equation,

$$W_{H2} = C\,Q\,G$$

Invoking the standard molar volume of 22.4 L/gram-mole, the rate of gas generation may be expressed in standard L/hr as:

$$Q_{H2} = C_1\,Q\,G$$

SNF-22059 provides a calculation for the fraction of power absorbed by water for each radiation type, whose results are provided in Table 1 of its Attachment 12. Note that g(H_2) values are defined on the basis of energy absorbed by water alone.

FATE requires inputs for the g(H_2) values and for the associated fraction of decay power. Therefore, to apply the SNF-22059 method using the FATE inputs, g(H_2) values are input for water as used in SNF-22059, and the associated fraction of decay power is the fraction for each radiation type deposited in water (the complementary fraction of the decay power is deposited in solids). So, FATE requires the products $f_{q\alpha}e_\alpha$, $f_{q\beta}e_\beta$, and $f_{q\gamma}e_\gamma$. These products will be found by obtaining appropriate values for the current sludge type power fractions $f_{q\alpha}$, $f_{q\beta}$, and $f_{q\gamma}$, and choosing appropriate values of e_α, e_β, and e_γ from SNF-22059.

The alpha, beta, and gamma decay power fractions for each sludge type are given by decay corrected to October 2013 in the spreadsheet *alpha beta and gamma decay fractions for sludge Rev 1.xlsx* by Michael E. Johnson, dated February 23, 2010. The decay fractions are summarized in Table A-9. In future work, this spreadsheet will be validated and the results will be combined with a revised calculation of the power deposition to water as mentioned above.

Table A-9: Fraction of Total Decay Energy, Reproduced from Michael E. Johnson, *alpha beta and gamma decay fractions for sludge Rev 1.xlsx,* February 23, 2010.

Sludge Type	Fraction of Total Decay Power		
	Alpha $f_{q\alpha}$	Beta $f_{q\beta}$	Gamma $f_{q\gamma}$
Settler	0.34	0.47	0.19
KW Container	0.36	0.43	0.21

The calculation of SNF-22059 was for different sludge types than those considered in this work. The reference sludge types whose properties match most closely those of the settler and container sludge are chosen. For settler sludge, SB canister sludge is chosen. For container sludge, N canister sludge is chosen. The comparison between the sludge properties of sludge of interest and matching sludge types is shown in Table A-10. As indicated in the main body of the report, this assumption will be relaxed in the future, and an exact calculation following the SNF-22059 method will be followed for the sludge types considered in this work.

Table A-10: Sludge Properties of Closest Match to SNF-22059 Reference Types

Sludge Type	Sludge Properties		
	Sludge Density g/cc	Total U g/cc	U metal g/cc
Settler (this work)	3.25	2.050	0.1625
SB Canister (SNF-22059)	2.50	1.400	0.125
KW Container (this work)	1.8	0.59	0.082
N Canister (SNF-22059)	1.90	0.770	0.0399

Table A-11 lists the fraction of energy deposited to water for alpha, beta, and gamma radiation for different sludge types taken from SNF-22059, Attachment 12, Table 1.

Table A-11: Fraction of Energy Deposited to Water from SNF-22059

Sludge Type	Sludge Type in SNF-22059	Fraction of Energy Deposited to Water		
		Alpha e_α	Beta e_β	Gamma e_γ
Settler	SB Canister	0.320	0.191	0.0253
KW Container	N Canister	0.329	0.251	0.0423

Finally, the fraction of total decay energy attributed to alpha, beta, and gamma in Table A-9 is multiplied by the fraction of energy deposited to water in Table A-11 to obtain the FATE radiolysis inputs as shown inTable A-12.

Table A-12: FATE Radiolysis Inputs – Fraction of Power Deposited to Water

Sludge Type	FATE Radiolysis Inputs		
	Alpha $f_{q\alpha}e_{\alpha}$ FALPSG	Beta $f_{q\beta}e_{\beta}$ FBETSG	Gamma $f_{q\gamma}e_{\gamma}$ FGAMSG
Settler	0.109	0.090	0.005
KW Container	0.118	0.108	0.009

The g value for each radiation type for radiolytic generation of hydrogen is input to FATE and is summarized in Table A-13. Consistent with SNF-22059, these are the values for pure water.

Table A-13: FATE Radiolysis Inputs – G Values

	FATE G Value Inputs, molecule H_2/100 eV absorbed in water		
Radiation	Alpha g_{α}	Beta g_{β}	Gamma g_{γ}
FATE parameter	GH2ALPSG	GH2BETSG	GH2GAMSG
Value	1.5	0.5	0.5

APPENDIX B: Appendix B: FATE™ INPUT FILES

B.1 Base File: CON2STSC1.dat

```
CONTROL
*
TITLE
**********************************************************************
*                                                                    *
*       CON3STSC1.DAT                                                *
*                                                                    *
*       BASE FILE FOR CONTAINER SLUDGE IN STSC (NO ANNULUS)          *
*                                                                    *
*       10 LAYERS IN HEAD, 10 LAYERS IN CYLINDRICAL SECTION          *
*       1.6 M**3 SLUDGE VOLUME REPRESENTED, SEGREGATED               *
*                                                                    *
*       STSC OD = 59", 1/2" SS WALL                                  *
*       SKIRT WITH HOLES                                             *
*                                                                    *
*       SLUDGE NODALIZATION AT LAYERS 13/14 ADJUSTED                 *
*       FOR 0.8 M**3 CUMULATIVE VOLUME THROUGH LAYER 13              *
*                                                                    *
**********************************************************************
END TITLE
*
 TIMING    ! Keyword
   TSTART         0.          !  START TIME, >0 FOR RESTART RUN
   TLAST   1728000.           !  END TIME (Seconds)        (20 days)
*
   DTMIN          0.01        ! MIN TIMESTEP (Seconds)
   DTMAX                      ! MAX TIMESTEP (Seconds)
         0.       0.2
       200.       0.5
       500.       1.0
      1000.       3.0
     10000.       3.0
   FRLXDT         0.2         ! RELAXATION FACTOR FOR FLOW ITERATION
   DTPRIN    14400.           ! PRINT INTERVAL (Seconds)
   PLTMIN      900.           ! MIN PLOT INTERVAL (Seconds)
   PLTMAX     3600.           ! MAX INTERVAL WITHOUT PLOT (Seconds)
   DTRST     86400.           ! RESTART INTERVAL (Seconds)
   FTPCH          0.005        ! FRACTIONAL CHANGE IN T AND P
   FAECH          1.E10        ! FRACTIONAL CHANGE IN AEROSOL MASS
   FPPLCH         0.03         ! FRACTIONAL CHANGE FOR PLOTTING
   TPOFST         0.0          ! OFFSET IN TIME IN PLOT FILES
 END TIMING
*
 COMPOUNDS 7
   STEAM OXYGEN NITROGEN HYDROGEN HELIUM ARGON WASTE
 END
PRINT-T

                                          68,1


                                                    63,1

                                                    62,1

59,20        59,15       59,10       59,5       59,1   58,1
56,20        56,15       56,10       56,5       56,1   55,1
53,20        53,15       53,10       53,5       53,1   52,1
50,20        50,15       50,10       50,5       50,1   49,1
47,20        47,15       47,10       47,5       47,1   46,1
```

```
44,20         44,15        44,10       44,5       44,1   43,1
41,20         41,15        41,10       41,5       41,1   40,1
38,20         38,15        38,10       38,5       38,1   37,1
35,20         35,15        35,10       35,5       35,1   34,1
32,20         32,15        32,10       32,5       32,1   31,1
29,20         29,15        29,10       29,5       29,1   28,1
26,20         26,15        26,10       26,5       26,1   25,1
23,19         23,14        23,9        23,4     23,1   22,1
20,18         20,13        20,8        20,3  20,1  19,1
17,16         17,11        17,6          17,1  16,1
14,15         14,10        14,5        14,1  13,1
11,14         11,9          11,3   11,1  10,1
8,12          8,7             8,1    7,1                 96,1
5,10          5,5          5,1    4,1
2,8           2,3     2,1



95,1
END PRINT-T
*
 CELSIUS
*
 PLOT 1
  PRESSURE      2    1  3
  GAS-T         2    1  3
  LIQ-T         1    1
  HS-TI         9       4  7 10 13 16 19 22 25 28
  HS-TI        10    31 34 37 40 43 46 49 52 55 58
  HS-TI         4    61 68 95 96
  QLIQ-HSI      7             12 15 18 21 24 27 30
  QLIQ-HSI     10    33 36 39 42 45 48 51 54 57 60
  QGAS-HSO      9       4  7 10 13 16 19 22 25 28
  QGAS-HSO     10    31 34 37 40 43 46 49 52 55 58
  QGAS-HSO      4    61 68 95 96
  QFIN          3     2  8 59
  QSW           9       5  8 11 14 17 20 23 26 29  ! Side loss/gain
  QSW          10    32 35 38 41 44 47 50 53 56 59
  GAS-X  NITROGEN    2   1   3                ! N2 %
  GAS-X  OXYGEN      2   1   3                ! O2 %
  GAS-X  STEAM       2   1   3                ! H2O %
  GAS-X  HYDROGEN    2   1   3                ! H2 %
  GAS-W              5   1   2   4   5   6    ! vent flow
  GAS-WX             5   1   2   4   5   6    ! vent cc flow
  HS-T  59     2     1  20
  HS-T  56     2     1  20
  HS-T  53     2     1  20
  HS-T  50     2     1  20
  HS-T  47     2     1  20
  HS-T  44     2     1  20
  HS-T  41     2     1  20
  HS-T  38     2     1  20
  HS-T  35     2     1  20
  HS-T  32     2     1  20
  HS-T  29     2     1  20
  HS-T  26     2     1  20
  HS-T  23     2     1  19
  HS-T  20     2     1  18
  HS-T  17     2     1  16
  HS-T  14     2     1  15
  HS-T  11     2     1  14
  HS-T   8     2     1  12
  HS-T   5     2     1  10
  HS-T   2     2     1   8
  WCOND-PL  STEAM    1   1      ! Condensation rate of steam on pool
  WCOND-HSI STEAM    1   68     ! Condensation rate of steam on STSC
  WCOND-HSO STEAM    1   68     ! Condensation rate of steam on STSC
  SPECIAL-R          6   301 302 303 304 305 309 ! Energy Balance Terms
  SPECIAL-R          3   306 307 312
  QGAS-HSI 2   95 96            ! Watch radiation & convection to skirt
```

```
  QGAS-HSO 9   4  7 10 13 16 19 22 25 28
  QGAS-HSO 2  95 96           ! Watch radiation & convection to skirt
  QRAD-HSI 2  95 96
  QRAD-HSO 9   4  7 10 13 16 19 22 25 28
  QRAD-HSO 2  95 96
 END PLOT  ! PLOT is a comment
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC    1    ! Junction flow
  ICCFLW   1    ! Counter-current flow
  IDIFLW   0    ! Diffusional transport
  IHSINK   1    ! Heat sinks
  IHXPOL   1    ! Pool-gas heat/mass transfer
  IHSBOIL 1     ! Boiling heat transfer
  ICNDS    1    ! Condensation
  IASED    0    ! Aerosol Sedimentation
  IALEAK   0    ! Aerosol Leakage
  IFOG     0    ! Fog formation
  IAEB     0    ! Aerosol release via sparging/boiling
  ISRC     1    ! User-defined sources
  IQDECAY 0     ! Assign decay power to compounds
  ILXFER   0    ! Liquid transfers
  IDCRT    0    ! DCRT
  ISLUDGE 1     ! Sludge
  IPLTYP   2    ! 1=wrap around, 2=no wrap (spreadsheet format)
 END ACTIVE MODELS
*
END CONTROL
*
VOLUMES
*
* UPPER OR LOWER HEAD
* ASSUME 1/2" WALL THICKNESS
* VOLUME OF ELLIPTICAL HEAD = 1/3*PI*(58/2)^3 = 25540.1 IN^3
* = 0.41853 M^3
*
* MIDDLE SECTION
* PI*(58/2)^2*72.63 = 191894 IN^3 = 3.14458 M^3
*
* VOLUME OF SLUDGE IN THE LOWER HEAD
* = 0.41853 M^3
*
* HEIGHT OF 1.6 M^3 SLUDGE IN THE CYLINDRICAL SECTION
* = (1.6 - 0.41853)/(PI*1.4732^2/4)
* = 0.69312 M
*
* INPUTS FOR REGION 1:
*   VOLUME = 2*0.41853 + 3.14458 - 1.6
*          = 2.38164 M^3
*   ELEVATION = 0.3683 + 0.69312 = 1.0614 M
*   SED_AREA = PI*1.4732^2/4 = 1.7046 M^2
*   Z_LIQ = 2.1750(85.63 IN) - 1.0614 = 1.1136 M
*   VOLUME OF WATER IN REGION 1
*     = 1.1136*PI*1.4732^2/4 = 1.8982 M^3
*   ZTOP = 1.1136*2.38164/1.8982 = 1.3972 M
*
 REGIONS        1           6             3
  LABEL         STSC        PROCESS-CELL  SKIRT
  VOLUME        1.8982      1.E9          0.2203
  SED_AREA      1.7046      1.E6          1.76
  ELEVATION     1.0614     -0.0254       -0.0254
  TEMP_GAS      35.0        35.00         35.0
  PRESSURE      1.01334E5   1.0E5         1.0E5
  ZTOP          1.3972      1.E3          0.3747
  Z_LIQ         1.1136      0.0           0.0
  TEMP_LIQ      35.0        35.0          35.0
 END REGIONS
*
* Gas composition of each region; specify mole fraction of each gas
*
 GASES          1           6             3
```

```
  STEAM        0.01          0.01          0.01
  OXYGEN       0.20          0.20          0.20
  NITROGEN     0.79          0.79          0.79
 END GASES
*
* Liquid composition of each region; specify mass fractions
*
 LIQUIDS        1             6             3
  STEAM        1.0           1.0           1.0
 END LIQUIDS
*
* Aerosol concentration of each region (kg/m^3)
*
* AEROSOLS       1          2          3
*  STEAM        0.0001     0.0        0.0
*  PART_DIA     1.0E-6     1.0E-6     1.0E-6    <--- optional
*  LOG_STD      1.4E0      1.4E0      1.4E0     <--- optional
* END AEROSOLS
*
*  OFFSET_TIMETG          50.
*  EXTRAPOLATION_TIMETG     LAST
*  TIMETG 1   0.0    100.     200.
*  TGFIX  1  30.00   30.00    30.00
*
*  OFFSET_TIMEPG          30.
*  EXTRAPOLATION_TIMEPG     EXTRAP
*  TIMEP 1   0.0    100.     200.
*  PRFIX 1   1.E5   1.2E5    1.4E5
*
END VOLUMES
*
JUNCTIONS
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
* ASSUME DISCHARGE COEFFICIENT OF 0.6, OR CJN=2.8
*
     PATHS        1             2
        LABEL    VENT-IN       VENT-OUT
        IJTYP    1             1
        IR1      6             1
        IR2      1             6
        IHORIZ   0             0
        XWJN     0.05080       0.1016
        XHJN     0.05080       0.1016
        XLJN     0.1699        0.7795
        AJN      2.03E-3       8.11E-3
        Z1JN     3.8148        1.5929
        Z2JN     1.5929        4.4244
        CJN      2.8           2.8
        FGAS1JN  1.0           1.0
     END PATHS
*
* HOLES IN THE SKIRT
*
* 11 HALF-HOLES AT THE BOTTOM
* 12 HOLES AT 3 INCH HEIGHT
* 12 HOLES AT 9.5 INCH HEIGHT
* HOLES ARE 4 INCH IN DIAMETER
*
     PATHS        4             5             6
        LABEL    HOLE-BOT      HOLE-MID      HOLE-TOP
        IJTYP    1             1             1
        IR1      6             6             3
        IR2      3             3             6
        IHORIZ   1             1             1
        XLJN     0.0127        0.0127        0.0127
        XHJN     0.1016        0.1016        0.1016
        XWJN     0.1016        0.1016        0.1016
        AJN      0.0446        0.0973        0.0973
```

```
        Z1JN      0.9906         1.0414         0.2413
        Z2JN      0.0254         0.0762         1.2065
        CJN       2.8            2.8            2.8
     END PATHS
*
END JUNCTIONS
*
HEAT_SINKS
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
SINKS        68
*
 LABEL       TOP
 IORIHS       2
 IGEOM        1
 IMATHS       2
 IMSLAB       3
 IREGI        1
 IREGO        6
 XRI         0.0
 XRO         0.01905
 AHS         2.380
 XLHS        1.524
 XZHS        1.524
 ZTHS        2.4586
 ZBHS        2.2131
 EHSO        0.30
 TIINIT      35.00
 TOINIT      35.00
END
*
* UNCOVERED PORTION OF STSC CYLINDER
*
* XZHS = 2.2131 - 2.1750 = 0.0381
*
* AHS = PI*(0.73660+0.74930)*0.0381 = 0.17785 M^2
*
* Assign STSC outer emissivities because STSC wall "sees"
* other STSC's.  Cut radiation down by 50%.
* Baseline overall value is 1/(1/0.44 + 1/0.6 - 1) = 0.34
* So desire overall = 0.17, 1/(1/x + 1/0.6 - 1) = 0.17, x = 0.192
*
*           Layer 22
SINKS        63
 LABEL       WALLI-22
 IORIHS      0
 IGEOM       0
 IMATHS      2
 IMSLAB      3
 IREGI       1
 IREGO       2
 XRI         0.73660
 XRO         0.74930
 AHS         0.17785
 XLHS        1.38
 XZHS        0.0381
 ZTHS        2.2131
 ZBHS        2.1750
 EHSO        0.192
 TIINIT      35.0
 TOINIT      35.0
END
*
* COVERED PORTION OF STSC CYLINDER
*
* XZHS = Z_LIQ = 1.1136
*
* AHS = PI*(0.73660+0.74930)*1.1136 = 5.1984 M^2
*           Layer 21
SINKS        62
 SAME_AS     63
```

```
 LABEL        WALLI-21
 AHS          5.1984
 XZHS         1.1136
 ZTHS         2.1750
 ZBHS         1.0614
END
*
* 10 LAYERS IN THE SLUDGE IN CYLINDERICAL SECTION
*
* XZHS = 0.69312/10 = 0.069312
* AHS = PI*(0.0+0.73660)*0.069312 = 0.16039 FOR SLUDGE
* AHS = PI*(0.73660+0.74930)*0.069312 = 0.32355 FOR STSC WALL
*
* AHHS1 = PI*1.4732^2/4
*       = 1.7046 M^2
*
* SLUDGE VOLUME PER LAYER IN CYLINDRICAL SECTION
* = PI*0.7366^2*0.069312 = 0.11815 M^3
*
*
* CUMULATIVE VOLUME IN THE ORIGINAL 20 LAYERS IS AS FOLLOWS:
*
*             Volume      Cumulative volume
* LAYER-20     0.11815      1.60003
* LAYER-19     0.11815      1.48188
* LAYER-18     0.11815      1.36373
* LAYER-17     0.11815      1.24558
*-------------------------------------------------------
* LAYER-16     0.11815      1.12743
* LAYER-15     0.11815      1.00928
* LAYER-14     0.11815      0.89113
*-------------------------------------------------------
* LAYER-13     0.11815      0.77298
* LAYER-12     0.11815      0.65483
* LAYER-11     0.11815      0.53668
* LAYER-10     0.07011      0.41853
*-------------------------------------------------------
* LAYER-9      0.06817      0.34842
* LAYER-8      0.06435      0.28025
* LAYER-7      0.05995      0.21590
* LAYER-6      0.06595      0.15595
* LAYER-5      0.04791      0.09000
* LAYER-4      0.01782      0.04209
* LAYER-3      0.01288      0.02427
* LAYER-2      0.00847      0.01139
* LAYER-1      0.00292      0.00292
*
* FOR METAL SEGREGATION AS 40% OF BATCH VOLUME,
* ADJUST LAYERS 9/10 SO THAT LAYER 9 ATTAINS
*   0.32 M**3 CUMULATIVE VOLUME
* VHS OF LAYER-9 = 0.06817 - (0.34842-0.32) = 0.03975
* AHS OF LAYER-9 = 0.14443*(0.03975/0.06817) = 0.08422
* ASHSO OF LAYER-9 = 0.19830*(0.03975/0.06817) = 0.11563
* VHS OF LAYER-10 = 0.07011 + (0.34842-0.32) = 0.09853
* AHS OF LAYER-10 = 0.09527*(0.09853/0.07011) = 0.13389
* ASHSO OF LAYER-10 = 0.19175*(0.09853/0.07011) = 0.26948
*
* ADJUST LAYERS 13/14 SO THAT LAYER 13 ATTAINS
*   0.80 M**3 CUMULATIVE VOLUME
* XZHS OF LAYER-13 = 0.069312*(0.80-0.65483)/(0.77298-0.65483)
*                  = 0.085163
* XZHS OF LAYER-14 = 2*0.069312 - 0.085163 = 0.053461
*
* SCALE AHS ACCORDINGLY.
* FOR LAYER-13, AHS = 0.16039*0.085163/0.069312 = 0.19707 FOR SLUDGE
*               AHS = 0.32355*0.085163/0.069312 = 0.39754 FOR WALL
* FOR LAYER-14, AHS = 0.16039*0.053461/0.069312 = 0.12371 FOR SLUDGE
*               AHS = 0.32355*0.053461/0.069312 = 0.24956 FOR WALL
*
* REVISED LAYERS NOW ARE:
*             Volume      Cumulative volume
```

```
* LAYER-14      0.09113       0.89113
*-----------------------------------------------------
* LAYER-13      0.14517       0.80000
*
*
* LAYER-10      0.32000       0.41853
*-----------------------------------------------------
* LAYER-9       0.03975       0.32
*
*            Layer 20
SINKS         59            58
 LABEL        SL-20         WALLO-20
 IORIHS       0             0
 IGEOM        0             0
 IMATHS       1             2
 IMSLAB       20            3
 IREGI        0             0
 IREGO        0             6
 XRI          0.0           0.73660
 XRO          0.73660       0.74930
 AHS          0.16039       0.32355
 XLHS         0.0           0.84
 XZHS         0.069312      0.0693120
 ZTHS         1.0614        1.0614
 ZBHS         0.99209       0.99209
 EHSO         0             0.192
 IREGS1       1             0
 AHSS1        1.7046        0.0
 TIINIT       35.0          35.0
 TOINIT       35.0          35.0
END
*            Layer 19
SINKS         56            55
 SAME_AS      59            58
 LABEL        SL-19         WALLO-19
 ZTHS         0.99209       0.99209
 ZBHS         0.92278       0.92278
 IREGS1       0           0
END
*            Layer 18
SINKS         53            52
 SAME_AS      56            55
 LABEL        SL-18         WALLO-18
 ZTHS         0.92278       0.92278
 ZBHS         0.85346       0.85346
END
*            Layer 17
SINKS         50            49
 SAME_AS      56            55
 LABEL        SL-17         WALLO-17
 ZTHS         0.85346       0.85346
 ZBHS         0.78415       0.78415
END
*            Layer 16
SINKS         47            46
 SAME_AS      56            55
 LABEL        SL-16         WALLO-16
 ZTHS         0.78415       0.78415
 ZBHS         0.71484       0.71484
END
*            Layer 15
SINKS         44            43
 SAME_AS      56            55
 LABEL        SL-15         WALLO-15
 ZTHS         0.71484       0.71484
 ZBHS         0.64553       0.64553
END
*            Layer 14
SINKS         41            40
 SAME_AS      56            55
 LABEL        SL-14         WALLO-14
```

```
 ZTHS         0.64553     0.64553
 ZBHS         0.59206     0.59206
 XZHS         0.053461    0.053461
 AHS          0.12371     0.24956
END
*            Layer 13
SINKS         38          37
 SAME_AS      56          55
 LABEL        SL-13       WALLO-13
 ZTHS         0.59206     0.59206
 ZBHS         0.50690     0.50690
 XZHS         0.085163    0.085163
 AHS          0.19707     0.39754
END
*            Layer 12
SINKS         35          34
 SAME_AS      56          55
 LABEL        SL-12       WALLO-12
 ZTHS         0.50690     0.50690
 ZBHS         0.43759     0.43759
 XZHS         0.06609     0.06609
END
*            Layer 11
SINKS         32          31
 SAME_AS      56          55
 LABEL        SL-11       WALLO-11
 ZTHS         0.43759     0.43759
 ZBHS         0.36830     0.36830
END
*
*  ELLIPTICAL SECTION
*
*  RADIUS R = R0*SQRT(1 - (Y - R0/2)^2/(R0/2)^2)
*     WHERE RO IS THE MAJOR RADIUS OF THE ELLIPTICAL HEAD
*     AND Y IS THE HEIGHT
*  VOLUME V = 4*PI*(R0/2*Y^2 - Y^3/3)
*
*            Y       RO       VO       SO
*
*            0.3683  0.73660  0.41853
* LAYER-10                    0.07011  0.19175
*            0.3270  0.73195  0.34842
* LAYER-9                     0.06817  0.19830
*            0.2858  0.71788  0.28025
* LAYER-8                     0.06435  0.21056
*            0.2448  0.69395  0.21590
* LAYER-7                     0.05995  0.23238
*            0.2032  0.65844  0.15595
* LAYER-6                     0.06595  0.33085
*            0.1500  0.59326  0.09000
* LAYER-5                     0.04791  0.35101
*            0.1000  0.50462  0.04209
* LAYER-4                     0.01782  0.19157
*            0.0750  0.44551  0.02427
* LAYER-3                     0.01288  0.19590
*            0.0508  0.37330  0.01139
* LAYER-2                     0.00847  0.21692
*            0.0254  0.26881  0.00292
* LAYER-1                     0.00292  0.22802
*            0.0     0.00000  0.00000
*
*            Layer 10
* STSC bottom head radiates to skirt or drip pan
* reset emissivity to 0.44
SINKS         29          28
 SAME_AS      56          55
 LABEL        SL-10       WALLO-10
 IMSLAB       20          3
 IREGO        0           3
 XRI          0.00000     0.73428
 XRO          0.73428     0.74698
```

```
 AHS          0.13389     0.19175
 ASHSO        0.26948     0.19175
 VHS          0.09853     -1
 XZHS         0.04130     0.04130
 ZTHS         0.3683      0.3683
 ZBHS         0.3270      0.3270
 EHSO         0.7         0.44
END
*           Layer 9
SINKS         26          25
 SAME_AS      29          28
 LABEL        SL-9        WALLO-9
 IMSLAB       20          3
 XRI          0.00000     0.73485
 XRO          0.73485     0.74755
 AHS          0.08422     0.19830
 ASHSO        0.11563     0.19830
 VHS          0.03975     -1
 XZHS         0.04120     0.04120
 ZTHS         0.3270      0.3270
 ZBHS         0.2858      0.2858
END
*           Layer 8
SINKS         23          22
 SAME_AS      29          28
 LABEL        SL-8        WALLO-8
 IMSLAB       19          3
 XRI          0.00000     0.70592
 XRO          0.70592     0.71862
 AHS          0.09093     0.21056
 ASHSO        0.21056     0.21056
 VHS          0.06435     -1
 XZHS         0.041       O.04747
 ZTHS         0.2858      0.2858
 ZBHS         0.2448      0.2448
END
*
* wall for Layer 7 and below is considered horizontal;
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
*
*           Layer 7
SINKS         20          19
 SAME_AS      29          28
 LABEL        SL-7        WALLO-7
 IORIHS       0           1
 IMSLAB       18          3
 XRI          0.00000     0.67620
 XRO          0.67620     0.68890
 AHS          0.08837     0.23238
 ASHSO        0.23238     0.23238
 VHS          0.05995     -1
 XZHS         0.04160     0.05469
 ZTHS         0.2448      0.2448
 ZBHS         0.2032      0.2032
END
*           Layer 6
SINKS         17          16
 SAME_AS      29          19
 LABEL        SL-6        WALLO-6
 IMSLAB       16          3
 XRI          0.00000     0.62585
 XRO          0.62585     0.63855
 AHS          0.10460     0.33083
 ASHSO        0.33083     0.33083
 VHS          0.06595     -1
 XZHS         0.05320     0.08413
 ZTHS         0.2032      0.2032
 ZBHS         0.1500      0.1500
END
*           Layer 5
```

```
SINKS         14          13
 SAME_AS      29          19
 LABEL        SL-5        WALLO-5
 IMSLAB       15          3
 XRI          0.00000     0.54894
 XRO          0.54894     0.56164
 AHS          0.08623     0.35507
 ASHSO        0.35507     0.35507
 VHS          0.04791     -1
 XZHS         0.0500      0.10177
 ZTHS         0.1500      0.1500
 ZBHS         0.100       0.100
END
*           Layer 4
SINKS         11          10
 SAME_AS      29          19
 LABEL        SL-4        WALLO-4
 IMSLAB       14          3
 XRI          0.00000     0.47507
 XRO          0.47507     0.48777
 AHS          0.03731     0.19413
 ASHSO        0.19413     0.19413
 VHS          0.01782     -1
 XZHS         0.025       0.06418
 ZTHS         0.100       0.100
 ZBHS         0.075       0.075
END
*           Layer 3
SINKS         8           7
 SAME_AS      29          19
 LABEL        SL-3        WALLO-3
 IMSLAB       12          3
 XRI          0.00000     0.40941
 XRO          0.40941     0.42211
 AHS          0.03113     0.19895
 ASHSO        0.19895     0.19895
 VHS          0.01288     -1
 XZHS         0.02420     0.07616
 ZBHS         0.075       0.075
 ZBHS         0.0508      0.0508
END
*           Layer 2
SINKS         5           4
 SAME_AS      29          19
 LABEL        SL-2        WALLO-2
 IMSLAB       10          3
 XRI          0.0         0.32106
 XRO          0.32106     0.33376
 AHS          0.02562     0.22121
 ASHSO        0.22121     0.22121
 VHS          0.00847     -1
 XZHS         0.0254      0.10753
 ZTHS         0.0508      0.0508
 ZBHS         0.0254      0.0254
END
*
* For layer 1, where STSC bottom head is nearly horizontal,
* set XRI of the bottom head to RO at the top of layer 1
* and expose underside of the sludge to gas
* AHSS2 = pi*0.26881^2 = 0.22701
*
*           Layer 1
SINKS         2
 SAME_AS      29
 LABEL        SL-1
 IMSLAB       8
 XRI          0.0
 XRO          0.26881
 AHS          0.02145
 VHS          0.00292
 XZHS         0.0265
```

```
 ZTHS         0.0254
 ZBHS         0.0
 IREGS2       3
 AHSS2        0.22802
END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
SINKS        96           95
 LABEL       SKIRT        DRIP-PAN
 IORIHS      0            1
 IGEOM       0            1
 IMATHS      2            2
 IMSLAB      3            3
 IREGI       3            3
 IREGO       6            6
 XRI         0.73660      0.0
 XRO         0.74930      0.0127
 AHS         1.83783      2.246
 XLHS        0.3937       0.150
 XZHS        0.3937       0.150
 ZTHS        0.3683      -0.0254
 ZBHS       -0.0254      -0.0381
 EHSO        0.192        0.44
 TIINIT      35.0         35.0
 TOINIT      35.0         35.0
END
*
* MATERIAL LIBRARY - specify material properties for material 'imaths'
* up to 20 (INMAT) materials can be specified
* the sludge properties (excluding EHSI & EHSO) are specified in the
* SLUDGE section
* SYNTAX:
MATERIAL LIBRARY
*  name           imaths   rho     khs    cp    qv    ehsi    ehso
  SLUDGE           1        0.      0.     0.    0.    0.7     0.7
  STAINLESS-STEEL 2        8000.   16.0   500.  0.    0.44    0.44
  CONCRETE         3        1850.   0.6    960.  0.    0.75    0.75
END
*
* container wall to the sludge
  SANDWICH  4  1000.  5
  SANDWICH  7  1000.  8
  SANDWICH 10  1000. 11
  SANDWICH 13  1000. 14
  SANDWICH 16  1000. 17
  SANDWICH 19  1000. 20
  SANDWICH 22  1000. 23
  SANDWICH 25  1000. 26
  SANDWICH 28  1000. 29
  SANDWICH 31  1000. 32
  SANDWICH 34  1000. 35
  SANDWICH 37  1000. 38
  SANDWICH 40  1000. 41
  SANDWICH 43  1000. 44
  SANDWICH 46  1000. 47
  SANDWICH 49  1000. 50
  SANDWICH 52  1000. 53
  SANDWICH 55  1000. 56
  SANDWICH 58  1000. 59
* sludge stack (starts with STSC bottom plate)
  COND_NETWORK NET=1   2  5  8 11 14 17 20 23 26 29
                      32 35 38 41 44 47 50 53 56 59
  ALIGN_NW     NET=1   8 10 12 14 15 16 18 19 20 20
                      20 20 20 20 20 20 20 20 20 20
*
* STSC wall
  COND_NETWORK NET=2   4  7 10 13 16 19 22 25 28
                      31 34 37 40 43 46 49 52 55 58  62  63  68
* sludge
```

```
  HS_GROUP GROUP=1      2  5  8 11 14 17 20 23 26 29
                       32 35 38 41 44 47 50 53 56 59
*
* between drip pan and STSC bottom head
* (layer 2, 3, and 4)
  RAD_NETWORK NET=1 95    -4      -7      -10
  FVIEWHS           0.1   -1      -1      -1
                    1.0    0.0     0.0     0.0
                    1.0    0.0     0.0     0.0
                    1.0    0.0     0.0     0.0
* between drip pan and STSC bottom head - continue
* (layer 5, 6, and 7)
  RAD_NETWORK NET=2 95    -13     -16     -19
  FVIEWHS           0.1   -1      -1      -1
                    1.0    0.0     0.0     0.0
                    1.0    0.0     0.0     0.0
                    1.0    0.0     0.0     0.0
* between skirt and STSC wall
* (layer 8, 9, and 10)
  RAD_NETWORK NET=3 96    -22   -25   -28
  FVIEWHS           0.1    -1      -1       -1
                    1.0     0.0     0.0      0.0
                    1.0     0.0     0.0      0.0
                    1.0     0.0     0.0      0.0
END HEAT_SINKS
*
*-----------------------------------------------------------------------
SLUDGE
*-----------------------------------------------------------------------
*
*  KW Container Sludge
*  Segregated into metal-bearing and non-metal layers
*  metal is 40% the volume of a 0.8 m**3 batch
*  Top-down by elevation:
*  Layers 17-20 non-metal
*  Layers 14-16 metal
*  Layers 10-13 non-metal
*  Layers 1-9   metal
*
ISTOP    1       ! = 0, continue even if negative non-U density
                 ! = 1, stop if negative non-U density
IPRX     1       ! = 0, constant particle size
                 !  =1, shrinking core model for depletion of area
IWSTRIP 2        !  vapor stripping model choice
                 ! = 0, no vapor stripping
                 ! = 1, sparging bubbles bypass the water pool
                 ! = 2, partial equilibrium if pool less than ZLBEQ deep
                 ! = 3, full equilibrium with the pool
ILAWSG   5       ! Reaction rate model flag:
                 ! = 0, McGillivrary/Ritchie
                 ! = 1, Pearce
                 ! = 2, Trimble
                 ! = 3, Databook (default)
                 ! = 4, Databook + Oxygen Free Trimble
                 ! = 5, New
! list of heat sinks comprising sludge
IHSSG 59 56 53 50
      47 44 41
      38 35 32 29
      26 23 20 17 14 11  8  5  2
! region containing each sludge heat sink
IRSLDG 1  1  1  1
       1  1  1
       1  1  1  1
       1  1  1  1  1  1  1  1  1
! wet sludge density, kg/m^3 wet sludge
RHOSG   1793.7 1793.7 1793.7 1793.7
        1809.4 1809.4 1809.4
        1793.7 1793.7 1793.7 1793.7
        1809.4 1809.4 1809.4 1809.4 1809.4 1809.4 1809.4 1809.4 1809.4
! void fraction of the sludge
```

```
FPORSG  0.74  0.74  0.74  0.74
        0.74  0.74  0.74
        0.74  0.74  0.74  0.74
        0.74  0.74  0.74  0.74  0.74  0.74  0.74  0.74  0.74
! Density of U metal, kg U_metal/m^3 wet sludge
! Optionally, user may specify TABLE-n or FIT-n for position dependent
! density; for this option, specify:
! XRHOUM  table#  enumeration of x-positions of the node
! YRHOUM  table#  enumeration of metal concentrations
! or
! YRHOUM fit# min-x  max-x  coeff0  coeff1  coeff2  coeff3  coeff4
!
RHOUM     0.0   0.0   0.0   0.0
        205.0 205.0 205.0
          0.0   0.0   0.0   0.0
        205.0 205.0 205.0 205.0 205.0 205.0 205.0 205.0 205.0
! density of all U, kg U in any chemical form/m^3 wet sludge
RHOUT   584.2 584.2 584.2 584.2
        598.7 598.7 598.7
        584.2 584.2 584.2 584.2
        598.7 598.7 598.7 598.7 598.7 598.7 598.7 598.7 598.7
! gas (h2) void fraction in the sludge
FGASSG  0.00  0.00  0.00  0.00
        0.00  0.00  0.00
        0.00  0.00  0.00  0.00
        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
!
KSLDG   0.7   0.7   0.7   0.7
        0.7   0.7   0.7
        0.7   0.7   0.7   0.7
        0.7   0.7   0.7   0.7   0.7   0.7   0.7   0.7   0.7
!
KGSG         0.17   ! thermal conductivity of the gas in the sludge
XDSG         0.000500 ! particle diameter, m                          rdc 090224
FOXSG        3      ! oxidation rate multiplier
FKSG         1      ! sludge thermal conductivity multiplier
                    ! (not applied to user specified KSLDG)
QSG        0.08814  ! decay power, W/kg-U, 52W/m^3*1m^3/590kg-U=0.08814W/kg-U
DUOX       7500     ! true density of U oxide compounds, kg/m^3
FWUOX      272.0    ! formula weight of U oxide compounds, kg/kg-mole
KUSG         3.90   ! thermal conductivity of U in sludge, W/m-C
KUO2SG       1.80   ! thermal conductivity of UO2 in sludge, W/m-C
KH2OSG       0.6    ! thermal conductivity of H2O in sludge, W/m-C
KNONUSG      1.3    ! thermal conductivity of non-U in sludge, W/m-C
CPUSG      120.0    ! specific heat of U in sludge, J/kg-C
CPUO2SG    240.0    ! specific heat of UO2 in sludge, J/kg-C
CPH2OSG   4180.0    ! specific heat of H2O in sludge, J/kg-C
CPNONUSG   700.0    ! specific heat of non-U in sludge, J/kg-C
ZLBEQ        0.10   ! pool depth for equilibrium of sludge offgas
FRADIOLY     1.0    ! radiolysis rate multiplier
!
! FROM SNF-22059, REVISION 0, ATTACHMENT 12, TABLE 1, N CANISTER
! AND 'ALPHA BETA AND GAMMA DECAY FRACTIONS FOR SLUDGE REV 1.XLSX'
!     BY MICHAEL E. JOHNSON, 23-FEB-10, KW Engineered Container Sludge
!
FALPSG       0.118  ! fraction of decay power from alpha dep. in water
                    ! 0.329*0.36 = 0.118
FBETSG       0.108  ! fraction of decay power from beta dep. in water
                    ! 0.251*0.43 = 0.108
FGAMSG       0.009  ! fraction of decay power from gamma dep. in water
                    ! 0.0423*0.21 = 0.009
!
GH2ALPSG     1.5    ! g(H2) molecules H2/100 eV alpha dep. in water
GH2BETSG     0.5    ! g(H2) molecules H2/100 eV beta dep. in water
GH2GAMSG     0.5    ! g(H2) molecules H2/100 eV gamma dep. in water
!
! User specified format for U-metal concentration in the sludge
! output. Each pair of integers designates the heat sink number
! followed by its node index.  Note that the node index starts from
! the outer surface of the heat sink and ends at the inner surface.
! For example, "4,5" designates the concentration in the innermost
```

```
! node of heat sink #4.
!
PRINT-M
59,20       59,10       59,1
56,20       56,10       56,1
53,20       53,10       53,1
50,20       50,10       50,1
47,20       47,10       47,1
44,20       44,10       44,1
41,20       41,10       41,1
38,20       38,10       38,1
35,20       35,10       35,1
32,20       32,10       32,1
29,20       29,10       29,1
23,19       23,8  23,1
17,16     17,1
11,14
8,12
5,10
2,8
END PRINT-M

END SLUDGE
```

B.2 Base File: SET1STSC1.dat

```
CONTROL
*
TITLE
**********************************************************************
*                                                                    *
*       SET1STSC1.DAT                                                *
*                                                                    *
*       BASE FILE FOR SETTLER SLUDGE IN STSC (WITH ANNULUS)          *
*                                                                    *
*       10 LAYERS IN HEAD, 2 LAYERS IN CYLINDRICAL SECTION           *
*       0.5 M**3 SETTLER SLUDGE, SEGREGATED                          *
*                                                                    *
*       STSC OD = 59", 1/2" SS WALL                                  *
*       24" ANNULUS OD, 17" SLUDGE WIDTH                             *
*       SKIRT WITH HOLES                                             *
*                                                                    *
**********************************************************************
END TITLE
*
 TIMING    ! Keyword
   TSTART        0.          ! START TIME, >0 FOR RESTART RUN
   TLAST   1728000.          ! END TIME (Seconds)         (20 days)
*
   DTMIN         0.01        ! MIN TIMESTEP (Seconds)
   DTMAX                     ! MAX TIMESTEP (Seconds)
         0.      0.2
       200.      0.5
       500.      1.0
      1000.      3.0
     10000.      3.0
   FRLXDT        0.2         ! RELAXATION FACTOR FOR FLOW ITERATION
   DTPRIN    14400.          ! PRINT INTERVAL (Seconds)
   PLTMIN      900.          ! MIN PLOT INTERVAL (Seconds)
   PLTMAX     3600.          ! MAX INTERVAL WITHOUT PLOT (Seconds)
   DTRST     86400.          ! RESTART INTERVAL (Seconds)
   FTPCH         0.005       ! FRACTIONAL CHANGE IN T AND P
   FAECH         1.E10       ! FRACTIONAL CHANGE IN AEROSOL MASS
   FPPLCH        0.03        ! FRACTIONAL CHANGE FOR PLOTTING
   TPOFST        0.0         ! OFFSET IN TIME IN PLOT FILES
 END TIMING
*
 COMPOUNDS 7
   STEAM OXYGEN NITROGEN HYDROGEN HELIUM ARGON WASTE
 END
*
 CELSIUS
*
 PLOT 1
  PRESSURE     3    1  2  3
  GAS-T        3    1  2  3
  LIQ-T        2    1  2
  HS-TI        9       4  7 10 13 16 19 22 25 28
  HS-TI       10   31 34 37 40 43 46 49 52 55 58
  HS-TI        4   61 68 95 96
  QLIQ-HSI     7             12 15 18 21 24 27 30
  QLIQ-HSI    10   33 36 39 42 45 48 51 54 57 60
  QGAS-HSO     9       4  7 10 13 16 19 22 25 28
  QGAS-HSO    10   31 34 37 40 43 46 49 52 55 58
  QGAS-HSO     4   61 68 95 96
  QFIN         3    2  8 35
  QSW          9    5  8 11 14 17 20 23 26 29 ! Side loss/gain
  QSW          2   32 35
  QSW          9    4  7 10 13 16 19 22 25 28 ! Side loss/gain
  QSW          2   31 34
  GAS-X  NITROGEN   3    1 2 3                ! N2 %
  GAS-X  OXYGEN     3    1 2 3                ! O2 %
  GAS-X  STEAM      3    1 2 3                ! H2O %
  GAS-X  HYDROGEN   3    1 2 3                ! H2 %
```

```
  GAS-W             2   1 2                     ! vent flow
  GAS-WX            2   1 2                     ! vent cc flow
  GAS-W             3   4 5 6                   ! skirt hole flow
  GAS-WX            3   4 5 6                   ! skirt hole cc flow
  HS-T  35    5     6   7   8   9   10
  HS-T  32    5     6   7   8   9   10
  HS-T  29    5     6   7   8   9   10
  HS-T  26    5     6   7   8   9   10
  HS-T  23    5     6   7   8   9   10
  HS-T  20    5     5   6   7   8    9
  HS-T  17    5     4   5   6   7    8
  HS-T  14    5     3   4   5   6    7
  HS-T  11    5     3   4   5   6    7
  HS-T   2    5     2   3   4   5    6
  SPECIAL-R         6   301 302 303 304 305 309 ! Energy Balance Terms
  SPECIAL-R         3   306 307 312
  QGAS-HSI 2  95 96           ! Watch radiation & convection to skirt
  QRAD-HSI 2  95 96
  QRAD-HSO 9  4  7 10 13 16 19 22 25 28
  QRAD-HSO 2  95 96
 END PLOT   ! PLOT is a comment
*
PRINT-T
                       68,1


                                                       61,1



                                                       58,1
                                                       55,1
                                                       52,1
                                                       49,1
                                                       46,1
                                                       43,1
                                                       40,1
                                                       37,1
                               35,20   35,9   35,1   34,1
                               32,20   32,9   32,1   31,1
                               29,20   29,9  29,1   28,1
                               26,20   26,9  26,1   25,1
                               23,19  23,9  23,1   22,1
                               20,17  20,8  20,1   19,1
                              17,16  17,8  17,1   16,1
                             14,14  14,7  14,1  13,1
                            11,13  11,6  11,1  10,1
                       8,19     8,15    8,1   7,1     96,1
                       5,15    5,7    5,1   4,1
                       2,13  2,7  2,1


                       95,1

END PRINT-T
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC    1    ! Junction flow
  ICCFLW   1    ! Counter-current flow
  IDIFLW   0    ! Diffusional transport
  IHSINK   1    ! Heat sinks
  IHXPOL   1    ! Pool-gas heat/mass transfer
  IHSBOIL  0    ! Boiling heat transfer
  ICNDS    1    ! Condensation
  IASED    0    ! Aerosol Sedimentation
  IALEAK   0    ! Aerosol Leakage
  IFOG     0    ! Fog formation
  IAEB     0    ! Aerosol release via sparging/boiling
  ISRC     1    ! User-defined sources
  IQDECAY  0    ! Assign decay power to compounds
  ILXFER   0    ! Liquid transfers
  IDCRT    0    ! DCRT
```

```
  ISLUDGE 1     ! Sludge
  IPLTYP  2     ! 1=wrap around, 2=no wrap (spreadsheet format)
 END ACTIVE MODELS
*
END CONTROL
*
VOLUMES
*
* UPPER OR LOWER HEAD
* ASSUME 1/2" WALL THICKNESS
* VOLUME OF ELLIPTICAL HEAD = 1/3*PI*(58/2)^3 = 25540.1 IN^3
* = 0.41853 M^3
*
* VOLUME OF INTERNAL CYLINDER IN UPPER HEAD
* (IGNORE 0.25" WALL THICKNESS) = PI*24^2/4*(58/4) = 6559.6 IN^3
* = 0.10749 M^3
*
* MIDDLE SECTION
* PI*(58/2)^2*72.63 = 191894 IN^3 = 3.14458 M^3
*
* VOLUME OF INTERNAL CYLINDER IN MIDDLE SECTION
* (IGNORE 0.25" WALL THICKNESS) = PI*24^2/4*72.63 = 32857.0 IN^3
* = 0.53843 M^3
*
* VOLUME OF INTERNAL CYLINDER IN LOWER HEAD
* = 1/3*PI*12^3 + PI*24^2/4*(14.5 - 2 - 6) = 4750 IN^3
* = 0.07784 M^3
*
* VOLUME OF SLUDGE IN THE LOWER HEAD
* = 0.41853 - 0.07784 = 0.34069 M^3
*
* HEIGHT OF 1 M^3 SLUDGE IN THE CYLINDRICAL SECTION
* = (1 - 0.34069)/(PI*(1.4732^2 - 0.6096^2)/4)
* = 0.46670 M
*
* INPUTS FOR REGION 1:
*   VOLUME = 2*0.41853 + 3.14458 - 0.72376(VOLUME OF REGION 3) - 1
*          = 2.25788 M^3
*   ELEVATION = 0.3683 + 0.46670 = 0.8350 M
*   SED_AREA = PI*(1.4732^2 - 0.6096^2)/4 = 1.4127 M^2
*   Z_LIQ = 2.175(85.63 IN) - 0.8350 = 1.340 M
*   VOLUME OF WATER IN REGION 1
*     = 1.340*PI*(1.4732^2 - 0.6096^2)/4 = 1.89302 M^3
*   ZTOP = 1.340*2.25788/1.89302 = 1.59827 M
*
* CHANGED FOR SETSTSC1.DAT:
*
* MODIFY REGION 1 INPUTS FOR 0.50 M**3 SLUDGE REMOVED
*   FROM ORIGINAL 1.0 M**3 SLUDGE:
*   VOLUME INCREASES BY 2.25788 + 0.50
*   ELEVATION TOP OF LAYER 12 0.48106, WAS 0.8350
*   ZLIQ = 2.175 - 0.48106 = 1.694
*   WATER VOLUME = 1.893 + 0.50 = 2.393
*   ZTOP = 1.694 * 2.75788/2.393 = 1.952
*
* REGION 3 - SKIRT
*   VOLUME = PI*59^2/4*(59/4) - 1/3*PI*(59/2)^3 = 1.344E4 IN^3 = 0.2203 M^3
*   ZTOP = 59/4 = 14.75 IN = 0.3747 M
*   ASED = PI*59^2/4* = 1.76 M^2
*
 REGIONS        1          6            2            3
  LABEL         STSC-OUTER  PROCESS-CELL STSC-INNER   SKIRT
  VOLUME        2.75788     1.E9        0.72376      0.2203
  SED_AREA      1.4127      1.E6        0.29186      1.76
  ELEVATION     0.48106    -0.0254      0.0508      -0.0254
  TEMP_GAS      35.0        35.00       35.0         35.0
  PRESSURE      1.0E5       1.0E5       1.0E5        1.0E5
  ZTOP          1.952       1.E3        2.47978      0.3747
  Z_LIQ         1.694       0.0         2.1242       0.0
  TEMP_LIQ      35.0        35.0        35.0         35.0
 END REGIONS
```

```
*
* Gas composition of each region; specify mole fraction of each gas
*
 GASES          1             6            2             3
  STEAM        0.01          0.01         0.01          0.01
  OXYGEN       0.20          0.20         0.20          0.20
  NITROGEN     0.79          0.79         0.79          0.79
 END GASES
*
* Liquid composition of each region; specify mass fractions
*
 LIQUIDS        1             6            2             3
  STEAM        1.0           1.0          1.0           1.0
 END LIQUIDS
*
* Aerosol concentration of each region (kg/m^3)
*
* AEROSOLS        1          2          3
*  STEAM        0.0001      0.0        0.0
*  PART_DIA     1.0E-6      1.0E-6     1.0E-6    <--- optional
*  LOG_STD      1.4E0       1.4E0      1.4E0     <--- optional
* END AEROSOLS
*
*  OFFSET_TIMETG           50.
*  EXTRAPOLATION_TIMETG      LAST
*  TIMETG 1   0.0    100.     200.
*  TGFIX  1  30.00   30.00    30.00
*
*  OFFSET_TIMEPG           30.
*  EXTRAPOLATION_TIMEPG      EXTRAP
*  TIMEP 1   0.0    100.     200.
*  PRFIX 1   1.E5   1.2E5    1.4E5
*
END VOLUMES
*
JUNCTIONS
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
* ASSUME DISCHARGE COEFFICIENT OF 0.6, OR CJN=2.8
*
     PATHS        1            2
        LABEL    VENT-IN      VENT-OUT
        IJTYP    1            1
        IR1      6            1
        IR2      2            6
        IHORIZ   0            0
        XWJN     0.05080      0.1016
        XHJN     0.05080      0.1016
        XLJN     0.1699       0.7795
        AJN      2.03E-3      8.11E-3
        Z1JN     3.8148       2.1732
        Z2JN     2.6035       4.4244
        CJN      2.8          2.8
        FGAS1JN  1.0          1.0
     END PATHS
*
* JUNCTION 3 REPRESENTS THE OPENING BETWEEN THE INNER CYLINDER AND STSC
* NEEDED FOR PRESSURE EQUALIZATION
* ACTUAL JUNCTION AREA AND RESISTANCE ARE NOT IMPORTANT
*
     PATHS        3
        LABEL    1-2
        IJTYP    1
        IR1      1
        IR2      2
        IHORIZ   0
        XLJN     0.01
        XHJN     0.025
        XWJN     0.025
```

```
        AJN       2.027E-3
        Z1JN      1.8189
        Z2JN      2.249
        CJN       2.8
     END PATHS
*
* HOLES IN THE SKIRT
*
* 11 HALF-HOLES AT THE BOTTOM
* 12 HOLES AT 3 INCH HEIGHT
* 12 HOLES AT 9.5 INCH HEIGHT
* HOLES ARE 4 INCH IN DIAMETER
*
     PATHS        4             5             6
        LABEL   HOLE-BOT      HOLE-MID      HOLE-TOP
        IJTYP     1             1             1
        IR1       6             6             3
        IR2       3             3             6
        IHORIZ    1             1             1
        XLJN      0.0127        0.0127        0.0127
        XHJN      0.1016        0.1016        0.1016
        XWJN      0.1016        0.1016        0.1016
        AJN       0.0446        0.0973        0.0973
        Z1JN      0.9906        1.0414        0.2413
        Z2JN      0.0254        0.0762        1.2065
        CJN       2.8           2.8           2.8
     END PATHS
*
END JUNCTIONS
*
HEAT_SINKS
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
*
SINKS        68
*
 LABEL       TOP
 IORIHS       2
 IGEOM        1
 IMATHS       2
 IMSLAB       3
 IREGI        1
 IREGO        6
 XRI         0.0
 XRO         0.01905
 AHS         2.380
 XLHS        1.524
 XZHS        1.524
 ZTHS        2.43327
 ZBHS        2.2131
 EHSO        0.30
 TIINIT      35.00
 TOINIT      35.00
END
*
* INNER CYLINDER AND STSC WALL ADJACENT TO WATER AND GAS
* NEGLECT INNER CYLINDER WALL IN THE UPPER ELLIPTICAL HEAD
*
* XZHS = 2.2131 - 0.8350 = 1.37810
*
* AHS = PI*(0.29845+0.30480)*1.37810 = 2.61173 M^2 FOR INNER CYLINDER WALL
* AHS = PI*(0.73660+0.74930)*1.37810 = 6.43310 M^2 FOR STSC WALL
*
*           Layer 21
SINKS        63                      61
 LABEL       WALLI-21                WALLO-21
 IORIHS      0                       0
 IGEOM       0                       0
 IMATHS      2                       2
 IMSLAB      3                       3
 IREGI       2                       1
```

```
 IREGO        1                   6
 XRI          0.29845             0.73660
 XRO          0.30480             0.74930
 AHS          2.61173             6.43310
 XLHS         1.38                1.38
 XZHS         1.3781              1.3781
 ZTHS         2.2131              2.2131
 ZBHS         0.8350              0.8350
 EHSO         0.30                0.30
 TIINIT       35.0                35.0
 TOINIT       35.0                35.0
END
*
* XZHS = 0.46670/10 = 0.046670
*
* AHS = PI*(0.29845+0.30480)*0.046670 = 0.08845 FOR INNER CYLINDER WALL
* AHS = PI*(0.30480+0.73660)*0.046670 = 0.15269 FOR SLUDGE
* AHS = PI*(0.73660+0.74930)*0.046670 = 0.21786 FOR STSC WALL
*
* AHHS1 = PI*(1.4732^2 - 0.6096^2)/4
*       = 1.4127 M^2
*
* SLUDGE VOLUME PER LAYER IN CYLINDRICAL SECTION
* = PI*(0.7366^2 - 0.3048^2)*0.046670 = 0.06593 M^3
*
*
*
* CUMULATIVE VOLUME IN THE ORIGINAL 20 LAYERS IS AS FOLLOWS:
*
*              Volume      Cumulative volume
* LAYER-20     0.06593       1.0000
* LAYER-19     0.06593       0.93407
* LAYER-18     0.06593       0.86814
* LAYER-17     0.06593       0.80221
* LAYER-16     0.06593       0.73628
*-------------------------------------------------------
* LAYER-15     0.06593       0.67035
* LAYER-14     0.06593       0.60442
* LAYER-13     0.06593       0.53849
*-------------------------------------------------------
* LAYER-12     0.06593       0.47256
* LAYER-11     0.06593       0.40663
* LAYER-10     0.05806       0.34070
* LAYER-9       0.05615       0.28264
* LAYER-8       0.05238       0.22649
*-------------------------------------------------------
* LAYER-7       0.04781       0.17411
* LAYER-6       0.05106       0.12630
* LAYER-5       0.03629       0.07524
* LAYER-4       0.01574       0.03895
* LAYER-3       0.01182       0.02321
* LAYER-2       0.00847       0.01139
* LAYER-1       0.00292       0.00292
*
* FOR METAL SEGREGATION AS 1/3 OF BATCH VOLUME,
* ADJUST LAYERS 12/13 SO THAT LAYER 12 ATTAINS
*   0.50 M**3 CUMULATIVE VOLUME
* THEN, LOWER METAL IS 0.17411/0.50 = 0.348 CLOSE
* ALSO, UPPER METAL IS 0.17035/0.50, CLOSER.
*
* SLUDGE CROSS-SECTIONAL AREA
* AXS = PI*(0.73660**2 - 0.30480**2) = 1.412700 M**2
* FACE AREAS AHS OF INNER WALL, SLUDGE, OUTER WALL ARE:
* 0.08845, 0.15269, 0.21786 M**2 RESPECTIVELY
*
* volume V-12 = 0.50 - 0.40663 = 0.09337
* height XZHS-12 = V12/AXS = 0.06609
* elevation ZTHS-12 = 0.41497 + 0.06609 = 0.48106
* area = old area * new height/old height
* height ratio = 0.06609/0.046670 = 1.41611
* so for sinks 36, 35, 34 new areas are:
```

```
* AHS = 0.12526, 0.21623, 0.30851
*
* volume V-13 = 0.53849 - 0.50 = 0.03849
* height XZHS-13 = 2*0.04667 - 0.06609 = 0.02725
* elevation ZBHS-13 = ZTHS-12 = 0.48106
* height ratio = 0.02725/0.04667 = 0.58389
* so for sinks 39, 38, 37 new areas are:
* AHS = 0.05164, 0.08915, 0.12721
*
* REVISED LAYERS NOW ARE:
*             Volume        Cumulative volume
* LAYER-13     0.03849       0.53849
*-----------------------------------------------------
* LAYER-12     0.09337       0.50000
*
*            Layer 20
SINKS        60           59           58
 LABEL       WALLI-20     SL-20        WALLO-20
 IORIHS      0            0            0
 IGEOM       0            0            0
 IMATHS      2            1            2
 IMSLAB      3            20           3
 IREGI       2            0            0
 IREGO       0            0            6
 XRI         0.29845      0.30480      0.73660
 XRO         0.30480      0.73660      0.74930
 AHS         0.08845      0.15269      0.21786
 XLHS        0.78         0.0          0.84
 XZHS        0.046670     0.046670     0.046670
 ZTHS        0.8350       0.8350       0.8350
 ZBHS        0.78833      0.78833      0.78833
 EHSO        0.30         0            0.30
 IREGS1      0            1            0
 AHSS1       0.0          1.4127       0.0
 TIINIT      35.0         35.0         35.0
 TOINIT      35.0         35.0         35.0
END
*            Layer 19
SINKS        57           56           55
 SAME_AS     60           59           58
 LABEL       WALLI-19     SL-19        WALLO-19
 ZTHS        0.78833      0.78833      0.78833
 ZBHS        0.74166      0.74166      0.74166
 IREGS1       0            0           0
END
*            Layer 18
SINKS        54           53           52
 SAME_AS     57           56           55
 LABEL       WALLI-18     SL-18        WALLO-18
 ZTHS        0.74166      0.74166      0.74166
 ZBHS        0.69499      0.69499      0.69499
END
*            Layer 17
SINKS        51           50           49
 SAME_AS     57           56           55
 LABEL       WALLI-17     SL-17        WALLO-17
 ZTHS        0.69499      0.69499      0.69499
 ZBHS        0.64832      0.64832      0.64832
END
*            Layer 16
SINKS        48           47           46
 SAME_AS     57           56           55
 LABEL       WALLI-16     SL-16        WALLO-16
 ZTHS        0.64832      0.64832      0.64832
 ZBHS        0.60165      0.60165      0.60165
END
*            Layer 15
SINKS        45           44           43
 SAME_AS     57           56           55
 LABEL       WALLI-15     SL-15        WALLO-15
 ZTHS        0.60165      0.60165      0.60165
```

```
 ZBHS         0.55498      0.55498      0.55498
END
*            Layer 14
SINKS         42           41           40
 SAME_AS      57           56           55
 LABEL        WALLI-14     SL-14        WALLO-14
 ZTHS         0.55498      0.55498      0.55498
 ZBHS         0.50831      0.50831      0.50831
END
*            Layer 13
SINKS         39           38           37
 SAME_AS      57           56           55
 LABEL        WALLI-13     SL-13        WALLO-13
 ZTHS         0.50831      0.50831      0.50831
 ZBHS         0.48106      0.48106      0.48106
 XZHS         0.02725      0.02725      0.02725
 AHS          0.05164      0.08915      0.12721
* ZBHS         0.46164      0.46164      0.46164
END
*            Layer 12
SINKS         36           35           34
 SAME_AS      57           56           55
 LABEL        WALLI-12     SL-12        WALLO-12
* ZTHS         0.46164      0.46164      0.46164
 ZTHS         0.48106      0.48106      0.48106
 ZBHS         0.41497      0.41497      0.41497
 XZHS         0.06609      0.06609      0.06609
 AHS          0.12526      0.21623      0.30851
END
*            Layer 11
SINKS         33           32           31
 SAME_AS      57           56           55
 LABEL        WALLI-11     SL-11        WALLO-11
 ZTHS         0.41497      0.41497      0.41497
 ZBHS         0.36830      0.36830      0.36830
END
*
*  ELLIPTICAL SECTION
*
*  RADIUS R = R0*SQRT(1 - (Y - R0/2)^2/(R0/2)^2)
*     WHERE RO IS THE MAJOR RADIUS OF THE ELLIPTICAL HEAD
*     AND Y IS THE HEIGHT
*  VOLUME V = 4*PI*(R0/2*Y^2 - Y^3/3)
*
*            Y        RI        VI        SI        RO        VO        SO        VO-VI
*
*            0.3683   0.30480   0.07783             0.73660   0.41853
* LAYER-10                      0.01205   0.07909             0.07011   0.19175   0.05806
*            0.3270   0.30480   0.06578             0.73195   0.34842
* LAYER-9                       0.01202   0.07890             0.06817   0.19830   0.05615
*            0.2858   0.30480   0.05376             0.71788   0.28025
* LAYER-8                       0.01197   0.07852             0.06435   0.21056   0.05238
*            0.2448   0.30480   0.04179             0.69395   0.21590
* LAYER-7                       0.01214   0.07967             0.05995   0.23238   0.04781
*            0.2032   0.30480   0.02965             0.65844   0.15595
* LAYER-6                       0.01489   0.11669             0.06595   0.33085   0.05106
*            0.1500   0.26766   0.01476             0.59326   0.09000
* LAYER-5                       0.01162   0.10230             0.04791   0.35101   0.03629
*            0.1000   0.22428   0.00314             0.50462   0.04209
* LAYER-4                       0.00208   0.07886             0.01782   0.19157   0.01574
*            0.0750   0.16481   0.00106             0.44551   0.02427
* LAYER-3                       0.00106   0.08625             0.01288   0.19590   0.01182
*            0.0508   0.0000    0.00000             0.37330   0.01139
* LAYER-2                       0.00000   0.00000             0.00847   0.21692   0.00847
*            0.0254   0.0000    0.00000             0.26881   0.00292
* LAYER-1                       0.00000   0.00000             0.00292   0.22802   0.00292
*            0.0      0.0000    0.00000             0.00000   0.00000
*
* lower head exterior sees atmosphere in the skirt enclosure
*
*            Layer 10
```

```
SINKS        30          29          28
 SAME_AS     57          56          55
 LABEL       WALLI-10    SL-10       WALLO-9
 IMSLAB       3          20          3
 IREGO        0           0          3
 XRI         0.29845     0.30480     0.73428
 XRO         0.30480     0.73428     0.74698
 AHS         0.07909     0.13482     0.19175
 ASHSI       0.07909     0.07909     0.19175
 ASHSO       0.07909     0.19175     0.19175
 VHS         -1          0.05806     -1
 XZHS        0.04130     0.04130     0.04130
 ZTHS        0.3683      0.3683      0.3683
 ZBHS        0.3270      0.3270      0.3270
END
*           Layer 9
SINKS        27          26          25
 SAME_AS     30          29          28
 LABEL       WALLI-9     SL-9        WALLO-9
 IMSLAB      3           20          3
 XRI         0.29845     0.30480     0.73485
 XRO         0.3048      0.73485     0.74755
 AHS         0.07890     0.14443     0.19830
 ASHSI       0.07890     0.07890     0.19830
 ASHSO       0.07890     0.19830     0.19830
 VHS         -1          0.05615     -1
 XZHS        0.04120     0.04120     0.04120
 ZTHS        0.3270      0.3270      0.3270
 ZBHS        0.2858      0.2858      0.2858
END
*           Layer 8
SINKS        24          23          22
 SAME_AS     30          29          28
 LABEL       WALLI-8     SL-8        WALLO-8
 IMSLAB      3           19          3
 XRI         0.29845     0.30480     0.70592
 XRO         0.30480     0.70592     0.71862
 AHS         0.07852     0.17215     0.21056
 ASHSI       0.07852     0.07852     0.21056
 ASHSO       0.07852     0.21056     0.21056
 VHS         -1          0.05238     -1
 XZHS        0.041       0.041       O.04747
 ZTHS        0.2858      0.2858      0.2858
 ZBHS        0.2448      0.2448      0.2448
END
*
* wall for Layer 7 and below is considered horizontal;
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
*
*           Layer 7
SINKS        21          20          19
 SAME_AS     30          29          28
 LABEL       WALLI-7     SL-7        WALLO-7
 IORIHS      0           0           1
 IMSLAB      3           17          3
 XRI         0.29845     0.30480     0.67620
 XRO         0.30480     0.67620     0.68890
 AHS         0.07884     0.12821     0.23238
 ASHSI       0.07884     0.07884     0.23238
 ASHSO       0.07884     0.23238     0.23238
 VHS         -1          0.04781     -1
 XZHS        0.0416      0.04160     0.05469
 ZTHS        0.2448      0.2448      0.2448
 ZBHS        0.2032      0.2032      0.2032
END
*           Layer 6
SINKS        18          17          16
 SAME_AS     30          29          19
 LABEL       WALLI-6     SL-6        WALLO-6
 IMSLAB      3           16          3
```

```
 XRI         0.27988     0.28623     0.62585
 XRO         0.28623     0.62585     0.63855
 AHS         0.11672     0.15244     0.33083
 ASHSI       0.11672     0.11672     0.33083
 ASHSO       0.11672     0.33083     0.33083
 VHS         -1          0.05106     -1
 XZHS        0.06490     0.05320     0.08413
 ZTHS        0.2032      0.2032      0.2032
 ZBHS        0.1500      0.1500      0.1500
END
*           Layer 5
SINKS        15          14          13
 SAME_AS     30          29          19
 LABEL       WALLI-5     SL-5        WALLO-5
 IMSLAB      3           14          3
 XRI         0.23962     0.24597     0.54894
 XRO         0.24597     0.54894     0.56164
 AHS         0.10099     0.12486     0.35507
 ASHSI       0.10099     0.10099     0.35507
 ASHSO       0.10099     0.35507     0.35507
 VHS         -1          0.03629     -1
 XZHS        0.06620     0.0500      0.10177
 ZTHS        0.1500      0.1500      0.1500
 ZBHS        0.100       0.100       0.100
END
*           Layer 4
SINKS        12          11          10
 SAME_AS     30          29          19
 LABEL       WALLI-4     SL-4        WALLO-4
 IMSLAB      3           13          3
 XRI         0.18820     0.19455     0.47507
 XRO         0.19455     0.47507     0.48777
 AHS         0.07757     0.05259     0.19413
 ASHSI       0.07757     0.07757     0.19413
 ASHSO       0.07757     0.19413     0.19413
 VHS         -1          0.01574     -1
 XZHS        0.06451     0.025       0.06418
 ZTHS        0.100       0.100       0.100
 ZBHS        0.075       0.075       0.075
END
*
* For layer 3, whose insert wall is nearly horizontal,
* do not model the inset waill. Instead, expose top
* of layer 3 to water, to 0.16481 m.
* AHSS1 = SI of third row = 0.08625 m^2
* IBSS1, beginning node to expose =
*   (1 + (0.40941 - 0.16481 - 0.01137)/0.02275) + 1 = 12
* IESS1, end node to expose = 19
*
* use effective XZHS considering 0.25 inch insert wall
*
*           Layer 3
SINKS                    8           7
 SAME_AS                 29          19
 LABEL                   SL-3        WALLO-3
 IMSLAB                  19          3
 XRI                     0.0         0.40941
 XRO                     0.40941     0.42211
 AHS                     0.03113     0.19895
 ASHSI                   0.0         0.19895
 ASHSO                   0.19895     0.19895
 VHS                     0.01182     -1
 XZHS                    0.0248      0.07616
 ZTHS                    0.075       0.075
 ZBHS                    0.0508      0.0508
 IREGS1                  2           0
 AHSS1                   0.08625     0.0
 IBSS1                   12          0
 IESS1                   19          0
END
*
```

```
* below the inner eliptical head
*
*           Layer 2
SINKS                   5            4
 SAME_AS                29           19
 LABEL                  SL-2         WALLO-2
 IMSLAB                 15           3
 XRI                    0.0          0.32106
 XRO                    0.32106      0.33376
 AHS                    0.02562      0.22121
 ASHSI                  0.0          0.22121
 ASHSO                  0.22121      0.22121
 VHS                    0.00847      -1
 XZHS                   0.0254       0.10753
 ZTHS                   0.0508       0.0508
 ZBHS                   0.0254       0.0254
END
*
* For layer 1, where STSC bottom head is nearly horizontal,
* set XRI of the bottom head to RO at the top of layer 1
* and expose underside of the sludge to gas
* AHSS2 = pi*0.26881^2 = 0.22701
*
*           Layer 1
SINKS                   2
 SAME_AS                29
 LABEL                  SL-1
 IMSLAB                 13
 XRI                    0.0
 XRO                    0.26881
 AHS                    0.02145
 VHS                    0.00292
 XZHS                   0.0265
 ZTHS                   0.0254
 ZBHS                   0.0
 IREGS2                 3
 AHSS2                  0.22802
END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
SINKS        96           95
 LABEL       SKIRT        DRIP-PAN
 IORIHS      0            1
 IGEOM       0            1
 IMATHS      2            2
 IMSLAB      3            3
 IREGI       3            3
 IREGO       6            6
 XRI         0.73660      0.0
 XRO         0.74930      0.0127
 AHS         1.83783      2.246
 XLHS        0.3937       0.150
 XZHS        0.3937       0.150
 ZTHS        0.3683       -0.0254
 ZBHS        -0.0254      -0.0381
 EHSO        0.136        0.3
 TIINIT      35.0         35.0
 TOINIT      35.0         35.0
END
*
* MATERIAL LIBRARY - specify material properties for material 'imaths'
* up to 20 (INMAT) materials can be specified
* the sludge properties (excluding EHSI & EHSO) are specified in the
* SLUDGE section
* SYNTAX:
MATERIAL LIBRARY
*  name           imaths   rho     khs    cp     qv    ehsi    ehso
  SLUDGE           1        0.      0.     0.     0.    0.7     0.7
  STAINLESS-STEEL 2        8000.   16.0   500.   0.    0.3     0.44
```

```
  CONCRETE        3      1850.   0.6   960.  0.    0.75    0.75
END
*
* container wall to the sludge
  SANDWICH  4  1000.  5
  SANDWICH  7  1000.  8
  SANDWICH 10  1000. 11     1000.  12
  SANDWICH 13  1000. 14     1000.  15
  SANDWICH 16  1000. 17     1000.  18
  SANDWICH 19  1000. 20     1000.  21
  SANDWICH 22  1000. 23     1000.  24
  SANDWICH 25  1000. 26     1000.  27
  SANDWICH 28  1000. 29     1000.  30
  SANDWICH 31  1000. 32     1000.  33
  SANDWICH 34  1000. 35     1000.  36
* REMOVE SLUDGE ABOVE LEVEL 12
*  SANDWICH 37  1000. 38     1000.  39
*  SANDWICH 40  1000. 41     1000.  42
*  SANDWICH 43  1000. 44     1000.  45
*  SANDWICH 46  1000. 47     1000.  48
*  SANDWICH 49  1000. 50     1000.  51
*  SANDWICH 52  1000. 53     1000.  54
*  SANDWICH 55  1000. 56     1000.  57
*  SANDWICH 58  1000. 59     1000.  60
* sludge stack (starts with STSC bottom plate)
*  COND_NETWORK NET=1   5 8 11 14 17 20 23 26
*                      29 32 35 38 41 44 47 50 53 56 59
*  ALIGN_NW     NET=1   1 2  5 11 15 17 19 20
*                      20 20 20 20 20 20 20 20 20 20 20
  COND_NETWORK NET=1   2 5 8 11 14 17 20 23 26
                     29 32 35
  ALIGN_NW     NET=1   1 2 5  8 11 15 17 19 20
                     20 20 20
*
* inner cylinder wall
  COND_NETWORK NET=3     12 15 18 21 24
                     27 30 33 36 39 42 45 48 51 54 57 60 63
* STSC wall
  COND_NETWORK NET=4   4  7 10 13 16 19 22
                     25 28 31 34 37 40 43 46 49 51 54 57 60
* sludge
*  HS_GROUP GROUP=1   2 5 8 11 14 17 20 23 26
*                    29 32 35 38 41 44 47 50 53 56 59
  HS_GROUP GROUP=1   2 5 8 11 14 17 20 23 26
                   29 32 35
*
* REMOVE SLUDGE ABOVE LEVEL 12:
*  CANCEL HS 38, 41, 44, 47, 50, 53, 56, 59
*  UPPER B.C. HS 35 CONVECTS TO WATER
  CANCEL 38
  CANCEL 41
  CANCEL 44
  CANCEL 47
  CANCEL 50
  CANCEL 53
  CANCEL 56
  CANCEL 59
  SINKS         35
    IREGS1       1
  END
* ADD CONVECTION BETWEEN WALLS AND ANNULUS WATER
*               inner     outer
  SINKS         60        58
    IREGI        2         1
    IREGO        1         6
  END
  SINKS         57        55
    IREGI        2         1
    IREGO        1         6
  END
  SINKS         54        52
```

```
    IREGI        2          1
    IREGO        1          6
  END
  SINKS         51         49
    IREGI        2          1
    IREGO        1          6
  END
  SINKS         48         46
    IREGI        2          1
    IREGO        1          6
  END
  SINKS         45         43
    IREGI        2          1
    IREGO        1          6
  END
  SINKS         42         40
    IREGI        2          1
    IREGO        1          6
  END
  SINKS         39         37
    IREGI        2          1
    IREGO        1          6
  END
*
* between drip pan and STSC bottom head
* (layer 2, 3, and 4)
  RAD_NETWORK NET=1 95   -4      -7      -10
  FVIEWHS          0.1   -1      -1      -1
                   1.0    0.0     0.0     0.0
                   1.0    0.0     0.0     0.0
                   1.0    0.0     0.0     0.0
* between drip pan and STSC bottom head - continue
* (layer 5, 6, and 7)
  RAD_NETWORK NET=2 95   -13     -16     -19
  FVIEWHS          0.1   -1      -1      -1
                   1.0    0.0     0.0     0.0
                   1.0    0.0     0.0     0.0
                   1.0    0.0     0.0     0.0
* between skirt and STSC wall
* (layer 8, 9, and 10)
  RAD_NETWORK NET=3 96    -22  -25  -28
  FVIEWHS          0.1    -1      -1       -1
                   1.0     0.0     0.0      0.0
                   1.0     0.0     0.0      0.0
                   1.0     0.0     0.0      0.0
END HEAT_SINKS
*
*-------------------------------------------------------------------
SLUDGE
*-------------------------------------------------------------------
*
*  50/50 KE/KW Settler Sludge
*  Segregated into metal-bearing and non-metal layers
*  metal is 1/3 the volume of a 0.5 m**3 batch
*  Top-down by elevation:
*  Layers 8-12  non-metal
*  Layers 1-7   metal
*
ISTOP   1       ! = 0, continue even if negative non-U density
                ! = 1, stop if negative non-U density
IPRX    1       ! = 0, constant particle size
                !  =1, shrinking core model for depletion of area
IWSTRIP 2       !  vapor stripping model choice
                ! = 0, no vapor stripping
                ! = 1, sparging bubbles bypass the water pool
                ! = 2, partial equilibrium if pool less than ZLBEQ deep
                ! = 3, full equilibrium with the pool
ILAWSG  5       ! Reaction rate model flag:
                ! = 0, McGillivrary/Ritchie
                ! = 1, Pearce
                ! = 2, Trimble
```

```
               ! = 3, Databook (default)
               ! = 4, Databook + Oxygen Free Trimble
               ! = 5, New
! list of heat sinks comprising sludge
IHSSG 35 32 29 26 23
      20 17 14 11  8  5  2
! region containing each sludge heat sink
IRSLDG 1  1  1  1  1
       1  1  1  1  1  1  1
! wet sludge density, kg/m^3 wet sludge
RHOSG   2954.1 2954.1 2954.1 2954.1 2954.1
        3822.6 3822.6 3822.6 3822.6 3822.6 3822.6 3822.6
! void fraction of the sludge
FPORSG  0.70  0.70  0.70  0.70  0.70
        0.70  0.70  0.70  0.70  0.70  0.70  0.70
! Density of U metal, kg U metal/m^3 wet sludge
! Optionally, user may specify TABLE-n or FIT-n for position dependent
! density; for this option, specify:
! XRHOUM  table#  enumeration of x-positions of the node
! YRHOUM  table#  enumeration of metal concentrations
! or
! YRHOUM fit# min-x  max-x  coeff0  coeff1  coeff2  coeff3  coeff4
!
RHOUM     0.0   0.0   0.0   0.0   0.0
        477.0 477.0 477.0 477.0 477.0 477.0 477.0
! density of all U, kg U in any chemical form/m^3 wet sludge
RHOUT   1716.4 1716.4 1716.4 1716.4 1716.4
        2695.5 2695.5 2695.5 2695.5 2695.5 2695.5 2695.5
! gas (h2) void fraction in the sludge
FGASSG  0.00  0.00  0.00  0.00        ! rdc 090225
        0.00  0.00  0.00  0.00        ! rdc 090225
        0.00  0.00  0.00  0.00        ! rdc 090225
!
KSLDG   0.7   0.7   0.7   0.7
        0.7   0.7   0.7   0.7
        0.7   0.7   0.7   0.7
!
KGSG         0.17   ! thermal conductivity of the gas in the sludge
XDSG         0.000375 ! particle diameter, m                        rdc 090224
FOXSG        3      ! oxidation rate multiplier
FKSG         1      ! sludge thermal conductivity multiplier
                    ! (not applied to user specified KSLDG)
QSG        0.09378  ! decay power, W/kg-U
DUOX       11100    ! true density of U oxide compounds, kg/m^3
FWUOX      272.0    ! formula weight of U oxide compounds, kg/kg-mole
KUSG         3.90   ! thermal conductivity of U in sludge, W/m-C
KUO2SG       1.80   ! thermal conductivity of UO2 in sludge, W/m-C
KH2OSG       0.6    ! thermal conductivity of H2O in sludge, W/m-C
KNONUSG      1.3    ! thermal conductivity of non-U in sludge, W/m-C
CPUSG      120.0    ! specific heat of U in sludge, J/kg-C
CPUO2SG    240.0    ! specific heat of UO2 in sludge, J/kg-C
CPH2OSG   4180.0    ! specific heat of H2O in sludge, J/kg-C
CPNONUSG   700.0    ! specific heat of non-U in sludge, J/kg-C
ZLBEQ        0.10   ! pool depth for equilibrium of sludge offgas
FRADIOLY     1.0    ! radiolysis rate multiplier
!
! FROM SNF-22059, REVISION 0, ATTACHMENT 12, TABLE 1, SB CANISTER
! AND 'ALPHA BETA AND GAMMA DECAY FRACTIONS FOR SLUDGE REV 1.XLSX'
!     BY MICHAEL E. JOHNSON, 23-FEB-10, Settler Sludge
!
FALPSG       0.109  ! fraction of decay power from alpha dep. in water
                    ! 0.320*0.34 = 0.109
FBETSG       0.090  ! fraction of decay power from beta dep. in water
                    ! 0.191*0.47 = 0.090
FGAMSG       0.005  ! fraction of decay power from gamma dep. in water
                    ! 0.0253*0.19 = 0.005
!
GH2ALPSG     1.5    ! g(H2) molecules H2/100 eV alpha dep. in water
GH2BETSG     0.5    ! g(H2) molecules H2/100 eV beta dep. in water
GH2GAMSG     0.5    ! g(H2) molecules H2/100 eV gamma dep. in water
!
```

```
! User specified format for U-metal concentration in the sludge
! output. Each pair of integers designates the heat sink number
! followed by its node index.  Note that the node index starts from
! the outer surface of the heat sink and ends at the inner surface.
! For example, "4,5" designates the concentration in the innermost
! node of heat sink #4.
!
PRINT-M
                         35,20      35,10      35,1
                         29,20      29,10     29,1
                         23,16      23,8  23,1
                         17,8    17,1
                         11,3
                        8,3
                       5,15
                     2,7
END PRINT-M

END SLUDGE
```

B.3 *Case File: CONTRF1.dat*

```
*------------------------------------------------------------------
CONTROL    ! Major keyword group
*------------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
*******************************************************************
*
*   CASE CONTRF1: STSC IN T-PLANT REGULAR CELL, FAN ON
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE CON2STSC1.DAT
*
*******************************************************************
  END TITLE
*
  TIMING
    TLAST     1728000.        !  END TIME (Seconds)
    DTMIN        0.01         !  MIN TIMESTEP (Seconds)
    DTMAX                     !  MAX TIMESTEP (Seconds)
    0.            0.2
    200.          0.5
    500.          1.0
    1000.         3.0
    10000.       10.0
    DTPRIN      86400.        !  PRINT INTERVAL (Seconds)
    PLTMIN       1000.        !  MIN PLOT INTERVAL (Seconds)
    PLTMAX      10000.        !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST       86400.        !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2        ! Keyword for plotting section
*
    PRESSURE      2    10 15                    ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10    101 102 103 106 107 108 111 112 113 114
    HS-TI        10    116 117 121 122 123 124 125 126 127 128
    HS-TI         3    131 132 133
    HS-TO         3    103 113 114
    QGAS-HSI      1    124
    HS-T  124    10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3   6  11 10                          ! N2 %
    GAS-X  OXYGEN     3   6  11 10                          ! O2 %
    GAS-X  STEAM      3   6  11 10                          ! H2O %
    GAS-X  HYDROGEN   3   6  11 10                          ! H2 %
    GAS-W            10    11 12 13 14 15 16 17 18 19 20
    GAS-W             9    21 22 24 25 26 27 28 29
    GAS-WX           10    11 12 13 14 15 16 17 18 19 20
    GAS-WX            9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other five containers containing settler sludge
* into T-CELL (6)
* 1 STSC:  1.6 m^3 * 590 Kg-U/m^3 * 0.08814 W/kg-U
*        =    83.2 W
* 5 STSCs: 416.0 W
*
* Oxidation (reaction) heat:
* 1 STSC: 116 W
* 5 STSCs: 5 * 116 W         = 580 W
```

```
*
* Total heat load for 5 STSCs: 996 W
*
* H2 Generation Rate:
* 1 STSC   = 838 l/day
*          = 838 l/day * 1/86400 day/s * 0.07598 kg/m**3 * 1/1000 m**3/l
*          = 7.37E-7 kg/s
* 5 STSCs:   3.69E-6 kg/s
*
  SOURCES 2
    REGION 6  GASES 1  PHASE 1
      HYDROGEN
      0      50.0     3.69E-6     996.0
      1.E9   50.0     3.69E-6     996.0
    END REGION
*
* Decay heat from six containers of container sludge in each of four
* cells in the Hot Cell (14)
* 4 * 6 * 83.2 W =              1996.8 W
*
* Oxidation (reaction) heat:
*  1 STSC:           116 W
* 24 STSCs: 4 * 6 * 116 W      = 2784.0 W
*
* Total heat load for 5 STSCs:   4780.8 W
*
* H2 Generation Rate:
*  1 STSC   = 7.37E-7 kg/s
* 24 STSCs  = 1.77E-5 kg/s
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.77E-5  4780.8
      1.E9   50.0    1.77E-5  4780.8
    END REGION
  END SOURCES
END CONTROL
*-------------------------------------------------------------------
VOLUMES
*-------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL         T-CELL
    VOLUME        114.63
    SED_AREA      16.82
    ELEVATION     -0.9906
    TEMP_GAS      35.0
    PRESSURE      1.0E5
    ZTOP          6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
```

```
* Volume: 31 * 143.08 m**3    = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS             7          11          12          14
    SAME_AS           6           6           6           6
    LABEL          COLD-CELL    CELL-2R    CELL-2L    HOT-CELL
    VOLUME          4435.48     222.71      251.39      458.52
    SED_AREA         521.42      33.21       33.21       67.28
    ELEVATION         -0.9906    -0.9906     -1.8542     -0.9906
    TEMP_GAS         32.0        32.0        32.0        32.0
    PRESSURE          1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP              6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES               7          11          12          14
    SAME_AS           6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS             8
    SAME_AS           6
    LABEL            VENT
    VOLUME          2023.0
    SED_AREA         632.1
    ELEVATION         -0.9906
    TEMP_GAS         32.0
    PRESSURE          1.0E5
    ZTOP              3.2
  END REGIONS
*
  GASES               8
    SAME_AS           6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
```

```
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
  REGIONS           9
    LABEL         PTRENCH
    VOLUME          951.45
    SED_AREA        520.26
    ELEVATION         4.3434
    ZTOP              1.83
    TEMP_GAS         23.0
    PRESSURE          1.0E5
  END REGIONS
*
  GASES             9
    SAME_AS         6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS          13           16
    SAME_AS         8            8
    LABEL         PIPE-24     EXH-DUCT
    VOLUME          2.9357     115.0
    SED_AREA        6.1316      53.88
    ELEVATION       1.7526      -0.9906
    ZTOP            0.6096       2.1336
    TEMP_GAS       32.0         32.0
    PRESSURE        1.0E5        1.0E5
  END REGIONS
*
  GASES            13           16
    SAME_AS         8            8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"        , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS          10               15
    LABEL         CANYON           AMBIENT
    VOLUME       40818.E0            1.E9
    SED_AREA      4245.E0            1.E6
    ELEVATION        7.5438          7.5438
    TEMP_GAS        32.0            25.0
    PRESSURE         1.0E5           1.0E5
    ZTOP            14.9352          1.E3
!    ZTOP            1.E3            1.E3
  END REGIONS
*
  GASES            10               15
    STEAM           0.01             0.01
    OXYGEN          0.20             0.20
    NITROGEN        0.79             0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
```

```
*
*  OFFSET_TIMEPG       0.0
*  EXTRAPOLATION_TIMEPG     PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                 50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-----------------------------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*            process cell      process cell      cell
*            long sidewall     short sidewall    cover block
  SINKS          101               102               103
*
    LABEL       PC-LSW            PC-SSW            PC-COV
    IORIHS         0                 0                 1
    IGEOM          1                 1                 1
    IMATHS         3                 3                 3
    XRI           0.0               0.0               0.0
    XRO           1.067             1.372             1.829
    AHS          72.217            53.141            21.337
    TIINIT       35.00             35.00             32.00
    TOINIT       35.00             35.00             35.00
    IMSLAB        20                20                20
    IREGI          6                 6                10
    IREGO          0                 0                 6
    XLHS         6.7056            6.7056            3.9624
    XZHS         6.7056            6.7056            3.9624
    ZTHS         5.7150            5.7150            7.5438
    ZBHS        -0.9906           -0.9906            5.7150
  END
*
*              31 COLD CELLS
*
*            long sidewall     short sidewall    cover block
  SINKS          106               107               108
*
    LABEL       CC-LSW            CC-SSW            CC-COV
    SAME_AS       101               102               103
    AHS          2.239E3           1.647E3           6.614E2
    TIINIT       32.00             32.00             32.00
    TOINIT       32.00             32.00             32.00
    IREGI          7                 7                10
    IREGO          0                 0                 7
  END
*
*              CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
```

```
*            long sidewall     long sidewall      short sidewall    cover
*            block
 SINKS          111              114                112                113
*
   LABEL        2R-LSW           2R-2L              2R-SSW             2R-COV
   SAME_AS       101             101                102                103
   AHS           56.206          56.206             53.141             33.213
   TIINIT        32.00           32.00              32.00              32.0
   TOINIT        32.00           32.00              32.00              32.0
   IREGI         11              11                 11                 10
   IREGO          0              12                 0                  11
 END
*
*              CELL 2L
*
*            long sidewall                          short sidewall
*
 SINKS          116                                   117
*
   LABEL        2L-LSW                                2L-SSW
   SAME_AS       111                                  112
   IREGI         12                                   12
   IREGO          0                                    0
 END
*
*               4 HOT CELLS
*
*                  long sidewall   short sidewall     cover block
 SINKS              126              127               128
*
   LABEL             CC-LSW           CC-SSW            CC-COV
   SAME_AS           101              102               103
   AHS               288.9            212.6             85.35
   IREGI             14               14                10
   IREGO             0                0                 14
 END
*
*               VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
 SINKS              121
*
   IORIHS             0
   IGEOM              1
   IMATHS             3
   XRI                0.0
   XRO                1.52
   AHS                1405.4
   TIINIT             32.0
   TOINIT             32.0
   IMSLAB             20
   IREGI              8
   IREGO              0
   XLHS               3.20
   XZHS               3.20
   ZTHS               2.21
   ZBHS               -0.9906
 END
*
*               CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
 SINKS              131              132
*
   IORIHS             0                0
   IGEOM              1                1
   IMATHS             3                3
   XRI               0.0              0.0
```

```
    XRO           1.52          0.915
    AHS          4090.0        2224.7
    TIINIT        32.00         32.00
    TOINIT        32.00         35.00
    IMSLAB         20            20
    IREGI          10            10
    IREGO           0             0
    XLHS          12.0          12.0
    XZHS          12.0          12.0
    ZTHS          15.394        19.664
    ZBHS          7.5438        15.394
  END
*
*            PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*            COVER IS    8 X (35 X 20) FT**2
*
*              wall             cover
  SINKS         122              123
*
    IORIHS         0               1
    IGEOM          1               1
    IMATHS         3               3
    XRI          0.0             0.0
    XRO          1.52            1.37
    AHS          781.0           520.5
    TIINIT        32.00           32.00
    TOINIT        32.00           32.00
    IMSLAB         20              20
    IREGI           9              10
    IREGO           0               9
    XLHS          1.83             1.83
    XZHS          1.83             1.83
    ZTHS          6.1710           7.5438
    ZBHS          4.3426           6.1710
  END
*
*           24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS            124              125
*
    IORIHS          0               0
    IGEOM           0               0
    IMATHS          3               3
    XRI             0.6096          0.3048
    XRO             5.0             0.6096
    AHS             177.3           2.8727
    TIINIT          32.00           32.00
    TOINIT          32.00           32.00
    IMSLAB          30              20
    IREGI           0               13
    IREGO           0               0
    XLHS            12.0            0.6096
    XZHS            10.1            10.1
!    ZTHS           ?               ?
!    ZBHS           ?               ?
  END
*
END HEAT_SINKS
*-----------------------------------------------------------------
JUNCTIONS
*-----------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
```

```
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP     8
    ICCJN     0
    IR1       6
    IR2       10
    IHORIZ    1
    AJN       1.0
    Z1JN      6.7056
    Z2JN      0.0
    CJN       1.E-5
    KFILTER  382.15
    FGAS1JN   1.0
    XLJN      1.0
    XWJN      1.0
    XHJN      1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP     8           8           8           8
    IR1       10          10          11          14
    IR2       7           9           10          10
    IHORIZ    1           1           1           1
    AJN       1.0         1.0         1.0         1.0
    Z1JN      0.0         0.0         6.7056      6.7056
    Z2JN      6.7056      1.83        0.0         0.0
    CJN       1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92       159.87      231.95      76.43
```

```
    FGAS1JN     1.0         1.0         1.0         1.0
    XLJN        1.0         1.0         1.0         1.0
    XWJN        1.0         1.0         1.0         1.0
    XHJN        1.0         1.0         1.0         1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
```

```
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13          14          21
    LABEL    COLD-VENT   VENT-TCELL  VENT-HOT
    IJTYP     1           1           1
    ICCJN     0           0           0
    IR1       7           8           8
    IR2       8           6          14
    IHORIZ    0           0           0
    AJN       1.7735      0.05067     0.25335
    Z1JN      2.7432      3.2004      3.2004
    Z2JN      3.2004      2.7432      2.7432
    CJN       2.8         2.8         2.8
    KFILTER   0.0         0.0         0.0
    FGAS1JN   1.0         1.0         1.0
    XLJN      2.5         2.5         2.5
    XWJN      0.254       0.254       0.254
    XHJN      0.254       0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS     16
    LABEL   PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN     0.9121
    Z1JN    0.0
    Z2JN    3.2004
    CJN     2.8
    FGAS1JN 1.0
    XLJN    2.5
    XWJN    0.254
    XHJN    0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
```

```
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS       19          20
    LABEL     C2L-PIPE  PIPE-C2R
    IJTYP      1           1
    ICCJN      0           0
    IR1       12          13
    IR2       13          11
    IHORIZ     0           0
    AJN       0.05067     0.05067
    Z1JN      5.5118      0.0
    Z2JN      0.0         5.5118
    CJN       2.8         2.8
    FGAS1JN   1.0         1.0
    XLJN      2.5         2.5
    XWJN      0.254       0.254
    XHJN      0.254       0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
```

```
* XHJN = 24" / sin(45) = 0.8621 m
*
  PATHS      25          27
    LABEL  VENT-EXH    PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0           0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS     26
    LABEL   FAN
    IJTYP    1
    ICCJN    1
    IR1     16
    IR2     15
    IHORIZ   0
    AJN      1.0
    Z1JN     0.0
    Z2JN    15.0
    CJN      1.0
    KFILTER  0.0
    FGAS1JN  1.0
    IFAN    1
    WVFAN    8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
```

```
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*       = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*       = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*       = 7.5692 m / 2
*       = 3.7846 m
*
  PATHS      28          29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP    8           8
    ICCJN    0           0
    IR1      15          15
    IR2      10          12
    IHORIZ   1           1
    AJN      1.0         1.0
    Z1JN     7.4676     -5.6134
    Z2JN     7.4676      3.7846
    CJN      2.8         2.8
    KFILTER  0.870       0.870
    FGAS1JN  1.0         1.0
    XLJN     1.0         1.0
    XWJN     1.0         1.0
    XHJN     1.0         1.0
  END PATHS
*
END JUNCTIONS
```

B.4 Case File: CONTLF1.dat

```
*-------------------------------------------------------------------
CONTROL    ! Major keyword group
*-------------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
*********************************************************************
*
*   CASE CONTLF1: STSC IN T-PLANT LONG CELL (2R), FAN ON
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE CON2STSC1.DAT
*
*********************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.        !  END TIME (Seconds)
    DTMIN       0.01         !  MIN TIMESTEP (Seconds)
    DTMAX                    !  MAX TIMESTEP (Seconds)
    0.           0.2
    200.         0.5
    500.         1.0
    1000.        3.0
    10000.      10.0
    DTPRIN     86400.        !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.        !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.        !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.        !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2      ! Keyword for plotting section
*
    PRESSURE      2    10 15                  ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10    101 102 103 106 107 108 111 112 113 114
    HS-TI        10    116 117 121 122 123 124 125 126 127 128
    HS-TI         3    131 132 133
    HS-TO         3    103 113 114
    QGAS-HSI      1    124
    HS-T  124    10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3    6  11 10                       ! N2 %
    GAS-X  OXYGEN     3    6  11 10                       ! O2 %
    GAS-X  STEAM      3    6  11 10                       ! H2O %
    GAS-X  HYDROGEN   3    6  11 10                       ! H2 %
    GAS-W              10    11 12 13 14 15 16 17 18 19 20
    GAS-W               9    21 22 24 25 26 27 28 29
    GAS-WX             10    11 12 13 14 15 16 17 18 19 20
    GAS-WX              9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other seven containers containing settler sludge
* into Cell 2R (11)
* 1 STSC:  1.6 m^3 * 590 Kg-U/m^3 * 0.08814 W/kg-U
*       =    83.2 W
* 7 STSCs: 582.4 W
*
* Oxidation (reaction) heat:
* 1 STSC: 116 W
* 7 STSCs: 7 * 116 W        = 812 W
```

```
*
* Total heat load for 7 STSCs: 1394.4 W
*
* H2 Generation Rate:
* 1 STSC   = 838 l/day
*          = 838 l/day * 1/86400 day/s * 0.07598 kg/m**3 * 1/1000 m**3/l
*          = 7.37E-7 kg/s
* 7 STSCs:   5.159E-6 kg/s
*
  SOURCES 2
    REGION 11 GASES 1  PHASE 1
      HYDROGEN
      0      50.0  5.159E-6   1394.4
      1.E9   50.0  5.159E-6   1394.4
    END REGION
*
* Decay heat from six containers of container sludge in each of four
* cells in the Hot Cell (14)
* 4 * 6 * 83.2 W =               1996.8 W
*
* Oxidation (reaction) heat:
*  1 STSC:           116 W
* 24 STSCs: 4 * 6 * 116 W      = 2784.0 W
*
* Total heat load for 5 STSCs:   4780.8 W
*
* H2 Generation Rate:
*  1 STSC   = 7.37E-7 kg/s
* 24 STSCs  = 1.77E-5 kg/s
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.77E-5  4780.8
      1.E9   50.0    1.77E-5  4780.8
    END REGION
  END SOURCES
END CONTROL
*-----------------------------------------------------------------------
VOLUMES
*-----------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS         6
    LABEL        T-CELL
    VOLUME       143.08
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES           6
    STEAM         0.01
    OXYGEN        0.20
    NITROGEN      0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
```

```
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS             7          11          12          14
    SAME_AS           6           6           6           6
    LABEL        COLD-CELL     CELL-2R    CELL-2L    HOT-CELL
    VOLUME         4435.48     185.11      251.39      458.52
    SED_AREA        521.42      33.21       33.21       67.28
    ELEVATION       -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS        32.0        32.0        32.0        32.0
    PRESSURE         1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP             6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES               7          11          12          14
    SAME_AS           6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS             8
    SAME_AS           6
    LABEL            VENT
    VOLUME         2023.0
    SED_AREA        632.1
    ELEVATION       -0.9906
    TEMP_GAS        32.0
    PRESSURE         1.0E5
    ZTOP             3.2
  END REGIONS
*
  GASES               8
    SAME_AS           6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
```

```
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
  REGIONS              9
    LABEL            PTRENCH
    VOLUME             951.45
    SED_AREA           520.26
    ELEVATION            4.3434
    ZTOP                 1.83
    TEMP_GAS            23.0
    PRESSURE             1.0E5
  END REGIONS
*
  GASES                9
    SAME_AS            6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS             13          16
    SAME_AS            8           8
    LABEL            PIPE-24    EXH-DUCT
    VOLUME             2.9357    115.0
    SED_AREA           6.1316     53.88
    ELEVATION          1.7526     -0.9906
    ZTOP               0.6096      2.1336
    TEMP_GAS          32.0        32.0
    PRESSURE           1.0E5       1.0E5
  END REGIONS
*
  GASES               13          16
    SAME_AS            8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"        , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS             10               15
    LABEL            CANYON          AMBIENT
    VOLUME          40818.E0           1.E9
    SED_AREA         4245.E0           1.E6
    ELEVATION           7.5438         7.5438
    TEMP_GAS           32.0           25.0
    PRESSURE            1.0E5          1.0E5
    ZTOP               14.9352         1.E3
!    ZTOP                1.E3           1.E3
  END REGIONS
*
  GASES               10               15
    STEAM              0.01            0.01
    OXYGEN             0.20            0.20
    NITROGEN           0.79            0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
```

```
*
*  OFFSET_TIMEPG       0.0
*  EXTRAPOLATION_TIMEPG     PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
               50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-------------------------------------------------------------------
HEAT_SINKS
*-------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*            process cell      process cell      cell
*            long sidewall     short sidewall    cover block
  SINKS          101              102               103
*
    LABEL       PC-LSW            PC-SSW            PC-COV
    IORIHS         0                0                 1
    IGEOM          1                1                 1
    IMATHS         3                3                 3
    XRI           0.0              0.0               0.0
    XRO           1.067            1.372             1.829
    AHS          72.217           53.141            21.337
    TIINIT       32.00            32.00             32.00
    TOINIT       32.00            32.00             35.00
    IMSLAB        20               20                20
    IREGI          6                6                10
    IREGO          0                0                 6
    XLHS         6.7056           6.7056            3.9624
    XZHS         6.7056           6.7056            3.9624
    ZTHS         5.7150           5.7150            7.5438
    ZBHS        -0.9906          -0.9906            5.7150
  END
*
*              31 COLD CELLS
*
*            long sidewall     short sidewall    cover block
  SINKS          106              107               108
*
    LABEL       CC-LSW            CC-SSW            CC-COV
    SAME_AS       101              102               103
    AHS          2.239E3          1.647E3           6.614E2
    TIINIT       32.00            32.00             32.00
    TOINIT       32.00            32.00             32.00
    IREGI          7                7                10
    IREGO          0                0                 7
  END
*
*              CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
```

```
*             long sidewall     long sidewall      short sidewall    cover
*             block
  SINKS         111               114                112               113
*
    LABEL         2R-LSW            2R-2L              2R-SSW            2R-COV
    SAME_AS       101               101                102               103
    AHS           56.206            56.206             53.141            33.213
    TIINIT        35.00             35.00              32.00             32.0
    TOINIT        35.00             35.00              32.00             32.0
    IREGI         11                11                 11                10
    IREGO          0                12                 0                 11
  END
*
*               CELL 2L
*
*             long sidewall                        short sidewall
*
  SINKS         116                                  117
*
    LABEL         2L-LSW                             2L-SSW
    SAME_AS       111                                112
    IREGI         12                                 12
    IREGO          0                                  0
  END
*
*              4 HOT CELLS
*
*                long sidewall  short sidewall     cover block
  SINKS           126             127                128
*
    LABEL          CC-LSW          CC-SSW             CC-COV
    SAME_AS        101             102                103
    AHS            288.9           212.6              85.35
    IREGI          14              14                 10
    IREGO          0               0                  14
  END
*
*              VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS           121
*
    IORIHS         0
    IGEOM          1
    IMATHS         3
    XRI            0.0
    XRO            1.52
    AHS            1405.4
    TIINIT         32.0
    TOINIT         32.0
    IMSLAB         20
    IREGI          8
    IREGO          0
    XLHS           3.20
    XZHS           3.20
    ZTHS           2.21
    ZBHS           -0.9906
  END
*
*              CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS           131             132
*
    IORIHS         0               0
    IGEOM          1               1
    IMATHS         3               3
    XRI           0.0             0.0
```

```
    XRO            1.52           0.915
    AHS           4090.0         2224.7
    TIINIT        32.00           32.00
    TOINIT        32.00           35.00
    IMSLAB         20              20
    IREGI          10              10
    IREGO           0               0
    XLHS          12.0            12.0
    XZHS          12.0            12.0
    ZTHS          15.394          19.664
    ZBHS          7.5438          15.394
  END
*
*             PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*             COVER IS    8 X (35 X 20) FT**2
*
*               wall             cover
  SINKS          122              123
*
    IORIHS          0               1
    IGEOM           1               1
    IMATHS          3               3
    XRI            0.0             0.0
    XRO            1.52            1.37
    AHS           781.0           520.5
    TIINIT        32.00           32.00
    TOINIT        32.00           32.00
    IMSLAB         20              20
    IREGI           9              10
    IREGO           0               9
    XLHS           1.83            1.83
    XZHS           1.83            1.83
    ZTHS          6.1710          7.5438
    ZBHS          4.3426          6.1710
  END
*
*            24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS          124              125
*
    IORIHS         0               0
    IGEOM          0               0
    IMATHS         3               3
    XRI            0.6096          0.3048
    XRO            5.0             0.6096
    AHS            177.3           2.8727
    TIINIT         32.00           32.00
    TOINIT         32.00           32.00
    IMSLAB         30              20
    IREGI          0               13
    IREGO          0               0
    XLHS           12.0            0.6096
    XZHS           10.1            10.1
!    ZTHS          ?               ?
!    ZBHS          ?               ?
  END
*
*-----------------------------------------------------------------
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
*
  SINKS        68
!   LABEL       TOP
    IREGO       11
  END
*
* INNER CYLINDER AND STSC WALL ADJACENT TO WATER AND GAS
```

```
*
*           Layer 21
  SINKS        61
!  LABEL       WALLO-21
   IREGO       11
  END
*
*             Volume      Cumulative volume
* LAYER-13     0.03849      0.53849
*---------------------------------------------------
* LAYER-12     0.09337      0.50000
*
*           Layer 20
  SINKS         58
   IREGO        11
  END
*           Layer 19
  SINKS         55
   IREGO        11
  END
*           Layer 18
  SINKS         52
   IREGO        11
  END
*           Layer 17
  SINKS         49
   IREGO        11
  END
*           Layer 16
  SINKS         46
   IREGO        11
  END
*           Layer 15
  SINKS         43
   IREGO        11
  END
*           Layer 14
  SINKS         40
   IREGO        11
  END
*           Layer 13
  SINKS         37
   IREGO        11
  END
*           Layer 12
  SINKS         34
   IREGO        11
  END
*           Layer 11
  SINKS         31
   IREGO        11
  END
*
*  ELLIPTICAL SECTION
*
* lower head exterior sees atmosphere in the skirt enclosure
*
*           Layer 10
  SINKS         28
   IREGO        11
  END
*           Layer 9
  SINKS         25
   IREGO        11
  END
*           Layer 8
  SINKS         22
   IREGO        11
  END
*
* wall for Layer 7 and below is considered horizontal;
```

```
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
*
*            Layer 7
  SINKS        19
    IREGO      11
  END
*            Layer 6
  SINKS        16
    IREGO      11
  END
*            Layer 5
  SINKS        13
    IREGO      11
  END
*            Layer 4
  SINKS        10
    IREGO      11
  END
*            Layer 3
  SINKS        7
    IREGO      11
  END
*
* below the inner eliptical head
*
*            Layer 2
  SINKS        4
    IREGO      11
  END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
  SINKS        96          95
!   LABEL      SKIRT        DRIP-PAN
    IREGO     11           11
  END
*
END HEAT_SINKS
*-------------------------------------------------------------------
JUNCTIONS
*-------------------------------------------------------------------
*
* Move STSC from region 6 to region 11
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
     PATHS        1            2
!       LABEL    VENT-IN      VENT-OUT
        IR1      11            1
        IR2       1           11
     END PATHS
*
* HOLES IN THE SKIRT
*
* Redirect from typical cell (6) to cell 2R (11)
*
     PATHS        4            5            6
!       LABEL   HOLE-BOT     HOLE-MID     HOLE-TOP
        IR1      11           11            3
        IR2       3            3           11
     END PATHS
*
*-------------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
```

```
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP      8
    ICCJN      0
    IR1        6
    IR2       10
    IHORIZ     1
    AJN        1.0
    Z1JN       6.7056
    Z2JN       0.0
    CJN        1.E-5
    KFILTER  382.15
    FGAS1JN    1.0
    XLJN       1.0
    XWJN       1.0
    XHJN       1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
```

```
    KFILTER   10.92      159.87     231.95      76.43
    FGAS1JN    1.0         1.0        1.0        1.0
    XLJN       1.0         1.0        1.0        1.0
    XWJN       1.0         1.0        1.0        1.0
    XHJN       1.0         1.0        1.0        1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
```

```
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13         14          21
    LABEL    COLD-VENT  VENT-TCELL  VENT-HOT
    IJTYP    1          1           1
    ICCJN    0          0           0
    IR1      7          8           8
    IR2      8          6           14
    IHORIZ   0          0           0
    AJN      1.7735     0.05067     0.25335
    Z1JN     2.7432     3.2004      3.2004
    Z2JN     3.2004     2.7432      2.7432
    CJN      2.8        2.8         2.8
    KFILTER  0.0        0.0         0.0
    FGAS1JN  1.0        1.0         1.0
    XLJN     2.5        2.5         2.5
    XWJN     0.254      0.254       0.254
    XHJN     0.254      0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS     16
    LABEL   PTRENCH-VENT
    IJTYP   1
    ICCJN   0
    IR1     9
    IR2     8
    IHORIZ  1
    AJN     0.9121
    Z1JN    0.0
    Z2JN    3.2004
    CJN     2.8
    FGAS1JN 1.0
    XLJN    2.5
    XWJN    0.254
    XHJN    0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
```

```
*       = 5.5118 m
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*       = ZTOP_12 - 6'9"
*       = 7.5692 m - 2.0574 m
*       = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      19          20
    LABEL    C2L-PIPE  PIPE-C2R
    IJTYP     1          1
    ICCJN     0          0
    IR1      12          13
    IR2      13          11
    IHORIZ    0          0
    AJN       0.05067    0.05067
    Z1JN      5.5118     0.0
    Z2JN      0.0        5.5118
    CJN       2.8        2.8
    FGAS1JN   1.0        1.0
    XLJN      2.5        2.5
    XWJN      0.254      0.254
    XHJN      0.254      0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*       = 4'
*       = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
```

```
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
*
  PATHS       25          27
    LABEL   VENT-EXH    PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0           0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       1.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
    KFILTER   0.0
    FGAS1JN   1.0
    IFAN     1
    WVFAN     8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
```

```
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS      28         29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP     8          8
    ICCJN     0          0
    IR1      15         15
    IR2      10         12
    IHORIZ    1          1
    AJN      1.0        1.0
    Z1JN     7.4676    -5.6134
    Z2JN     7.4676     3.7846
    CJN      2.8        2.8
    KFILTER  0.870      0.870
    FGAS1JN  1.0        1.0
    XLJN     1.0        1.0
    XWJN     1.0        1.0
    XHJN     1.0        1.0
  END PATHS
*
END JUNCTIONS
```

B.5 Case File: CONTRN1.dat

```
*---------------------------------------------------------------
CONTROL    ! Major keyword group
*---------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
*********************************************************************
*
*   CASE CONTRN1: STSC IN T-PLANT REGULAR CELL, FAN OFF
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE CON2STSC1.DAT
*
*********************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.       !  END TIME (Seconds)
    DTMIN       0.01        !  MIN TIMESTEP (Seconds)
    DTMAX                   !  MAX TIMESTEP (Seconds)
    0.           0.2
    200.         0.5
    500.         1.0
    1000.        3.0
    10000.      10.0
    DTPRIN     86400.       !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.       !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.       !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.       !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2       ! Keyword for plotting section
*
    PRESSURE      2    10 15                  ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10    101 102 103 106 107 108 111 112 113 114
    HS-TI        10    116 117 121 122 123 124 125 126 127 128
    HS-TI         3    131 132 133
    HS-TO         3    103 113 114
    QGAS-HSI      1    124
    HS-T  124    10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3    6   11 10                     ! N2 %
    GAS-X  OXYGEN     3    6   11 10                     ! O2 %
    GAS-X  STEAM      3    6   11 10                     ! H2O %
    GAS-X  HYDROGEN   3    6   11 10                     ! H2 %
    GAS-W             10    11 12 13 14 15 16 17 18 19 20
    GAS-W              9    21 22 24 25 26 27 28 29
    GAS-WX            10    11 12 13 14 15 16 17 18 19 20
    GAS-WX             9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other five containers containing settler sludge
* into T-CELL (6)
* 1 STSC:  1.6 m^3 * 590 Kg-U/m^3 * 0.08814 W/kg-U
*       =   83.2 W
* 5 STSCs: 416.0 W
*
* Oxidation (reaction) heat:
* 1 STSC: 116 W
* 5 STSCs: 5 * 116 W         = 580 W
```

```
*
* Total heat load for 5 STSCs: 996 W
*
* H2 Generation Rate:
* 1 STSC    = 838 l/day
*           = 838 l/day * 1/86400 day/s * 0.07598 kg/m**3 * 1/1000 m**3/l
*           = 7.37E-7 kg/s
* 5 STSCs:    3.69E-6 kg/s
*
  SOURCES 2
    REGION 6  GASES 1  PHASE 1
      HYDROGEN
      0      50.0     3.69E-6      996.0
      1.E9   50.0     3.69E-6      996.0
    END REGION
*
* Decay heat from six containers of container sludge in each of four
* cells in the Hot Cell (14)
* 4 * 6 * 83.2 W =              1996.8 W
*
* Oxidation (reaction) heat:
*  1 STSC:           116 W
* 24 STSCs: 4 * 6 * 116 W      = 2784.0 W
*
* Total heat load for 5 STSCs:   4780.8 W
*
* H2 Generation Rate:
*  1 STSC    = 7.37E-7 kg/s
* 24 STSCs   = 1.77E-5 kg/s
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0     1.77E-5  4780.8
      1.E9   50.0     1.77E-5  4780.8
    END REGION
  END SOURCES
END CONTROL
*-------------------------------------------------------------------
VOLUMES
*-------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL        T-CELL
    VOLUME       114.63
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
```

```
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS            7          11          12          14
    SAME_AS          6           6           6           6
    LABEL        COLD-CELL     CELL-2R     CELL-2L    HOT-CELL
    VOLUME          4435.48     222.71      251.39      458.52
    SED_AREA         521.42      33.21       33.21       67.28
    ELEVATION        -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS          32.0        32.0        32.0        32.0
    PRESSURE          1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP              6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES              7          11          12          14
    SAME_AS          6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            8
    SAME_AS          6
    LABEL           VENT
    VOLUME         2023.0
    SED_AREA        632.1
    ELEVATION        -0.9906
    TEMP_GAS         32.0
    PRESSURE          1.0E5
    ZTOP              3.2
  END REGIONS
*
  GASES              8
    SAME_AS          6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
```

```
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
  REGIONS            9
    LABEL          PTRENCH
    VOLUME          951.45
    SED_AREA        520.26
    ELEVATION         4.3434
    ZTOP              1.83
    TEMP_GAS         23.0
    PRESSURE          1.0E5
  END REGIONS
*
  GASES              9
    SAME_AS          6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            13          16
    SAME_AS          8           8
    LABEL          PIPE-24    EXH-DUCT
    VOLUME           2.9357    115.0
    SED_AREA         6.1316     53.88
    ELEVATION        1.7526     -0.9906
    ZTOP             0.6096      2.1336
    TEMP_GAS        32.0        32.0
    PRESSURE         1.0E5       1.0E5
  END REGIONS
*
  GASES              13          16
    SAME_AS          8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"        , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS            10               15
    LABEL            CANYON          AMBIENT
    VOLUME         40818.E0            1.E9
    SED_AREA        4245.E0            1.E6
    ELEVATION          7.5438          7.5438
    TEMP_GAS          32.0            25.0
    PRESSURE           1.0E5           1.0E5
    ZTOP              14.9352          1.E3
!    ZTOP              1.E3            1.E3
  END REGIONS
*
  GASES              10               15
    STEAM            0.01             0.01
    OXYGEN           0.20             0.20
    NITROGEN         0.79             0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
```

```
*
*  OFFSET_TIMEPG       0.0
*  EXTRAPOLATION_TIMEPG    PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-----------------------------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*             process cell      process cell      cell
*             long sidewall     short sidewall    cover block
  SINKS            101              102              103
*
    LABEL        PC-LSW           PC-SSW           PC-COV
    IORIHS          0                0                1
    IGEOM           1                1                1
    IMATHS          3                3                3
    XRI            0.0              0.0              0.0
    XRO            1.067            1.372            1.829
    AHS           72.217           53.141           21.337
    TIINIT        35.00            35.00            32.00
    TOINIT        35.00            35.00            35.00
    IMSLAB         20               20               20
    IREGI           6                6               10
    IREGO           0                0                6
    XLHS          6.7056           6.7056           3.9624
    XZHS          6.7056           6.7056           3.9624
    ZTHS          5.7150           5.7150           7.5438
    ZBHS         -0.9906          -0.9906           5.7150
  END
*
*               31 COLD CELLS
*
*             long sidewall     short sidewall    cover block
  SINKS            106              107              108
*
    LABEL        CC-LSW           CC-SSW           CC-COV
    SAME_AS        101              102              103
    AHS           2.239E3          1.647E3          6.614E2
    TIINIT        32.00            32.00            32.00
    TOINIT        32.00            32.00            32.00
    IREGI           7                7               10
    IREGO           0                0                7
  END
*
*               CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
```

```
*              long sidewall      long sidewall       short sidewall     cover
*              block
  SINKS            111              114                 112                113
*
    LABEL          2R-LSW           2R-2L               2R-SSW             2R-COV
    SAME_AS         101             101                 102                103
    AHS             56.206          56.206              53.141             33.213
    TIINIT          32.00           32.00               32.00              32.0
    TOINIT          32.00           32.00               32.00              32.0
    IREGI           11              11                  11                 10
    IREGO            0              12                  0                  11
  END
*
*               CELL 2L
*
*              long sidewall                          short sidewall
*
  SINKS            116                                  117
*
    LABEL          2L-LSW                               2L-SSW
    SAME_AS         111                                 112
    IREGI           12                                  12
    IREGO            0                                   0
  END
*
*               4 HOT CELLS
*
*                 long sidewall  short sidewall     cover block
  SINKS            126              127                 128
*
    LABEL           CC-LSW          CC-SSW              CC-COV
    SAME_AS         101             102                 103
    AHS             288.9           212.6               85.35
    IREGI           14              14                  10
    IREGO           0               0                   14
  END
*
*               VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS            121
*
    IORIHS          0
    IGEOM           1
    IMATHS          3
    XRI             0.0
    XRO             1.52
    AHS             1405.4
    TIINIT          32.0
    TOINIT          32.0
    IMSLAB          20
    IREGI           8
    IREGO           0
    XLHS            3.20
    XZHS            3.20
    ZTHS            2.21
    ZBHS            -0.9906
  END
*
*               CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS            131              132
*
    IORIHS          0               0
    IGEOM           1               1
    IMATHS          3               3
    XRI            0.0             0.0
```

```
    XRO            1.52          0.915
    AHS           4090.0        2224.7
    TIINIT        32.00          32.00
    TOINIT        32.00          35.00
    IMSLAB         20             20
    IREGI          10             10
    IREGO           0              0
    XLHS          12.0           12.0
    XZHS          12.0           12.0
    ZTHS          15.394         19.664
    ZBHS          7.5438         15.394
  END
*
*            PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*            COVER IS    8 X (35 X 20) FT**2
*
*              wall           cover
  SINKS         122            123
*
    IORIHS          0              1
    IGEOM           1              1
    IMATHS          3              3
    XRI           0.0            0.0
    XRO           1.52           1.37
    AHS          781.0          520.5
    TIINIT       32.00          32.00
    TOINIT       32.00          32.00
    IMSLAB        20             20
    IREGI          9             10
    IREGO          0              9
    XLHS          1.83           1.83
    XZHS          1.83           1.83
    ZTHS         6.1710         7.5438
    ZBHS         4.3426         6.1710
  END
*
*           24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS         124            125
*
    IORIHS        0              0
    IGEOM         0              0
    IMATHS        3              3
    XRI           0.6096         0.3048
    XRO           5.0            0.6096
    AHS           177.3          2.8727
    TIINIT        32.00          32.00
    TOINIT        32.00          32.00
    IMSLAB        30             20
    IREGI         0              13
    IREGO         0              0
    XLHS          12.0           0.6096
    XZHS          10.1           10.1
!    ZTHS         ?              ?
!    ZBHS         ?              ?
  END
*
END HEAT_SINKS
*-------------------------------------------------------------------
JUNCTIONS
*-------------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
```

```
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP      8
    ICCJN      0
    IR1        6
    IR2       10
    IHORIZ     1
    AJN        1.0
    Z1JN       6.7056
    Z2JN       0.0
    CJN        1.E-5
    KFILTER  382.15
    FGAS1JN    1.0
    XLJN       1.0
    XWJN       1.0
    XHJN       1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92      159.87      231.95       76.43
```

```
    FGAS1JN     1.0         1.0         1.0         1.0
    XLJN        1.0         1.0         1.0         1.0
    XWJN        1.0         1.0         1.0         1.0
    XHJN        1.0         1.0         1.0         1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
```

```
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13         14         21
    LABEL    COLD-VENT  VENT-TCELL VENT-HOT
    IJTYP    1          1          1
    ICCJN    0          0          0
    IR1      7          8          8
    IR2      8          6          14
    IHORIZ   0          0          0
    AJN      1.7735     0.05067    0.25335
    Z1JN     2.7432     3.2004     3.2004
    Z2JN     3.2004     2.7432     2.7432
    CJN      2.8        2.8        2.8
    KFILTER  0.0        0.0        0.0
    FGAS1JN  1.0        1.0        1.0
    XLJN     2.5        2.5        2.5
    XWJN     0.254      0.254      0.254
    XHJN     0.254      0.254      0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      16
    LABEL    PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN      0.9121
    Z1JN     0.0
    Z2JN     3.2004
    CJN      2.8
    FGAS1JN  1.0
    XLJN     2.5
    XWJN     0.254
    XHJN     0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
```

```
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS       19          20
    LABEL     C2L-PIPE  PIPE-C2R
    IJTYP      1           1
    ICCJN      0           0
    IR1       12          13
    IR2       13          11
    IHORIZ     0           0
    AJN        0.05067     0.05067
    Z1JN       5.5118      0.0
    Z2JN       0.0         5.5118
    CJN        2.8         2.8
    FGAS1JN    1.0         1.0
    XLJN       2.5         2.5
    XWJN       0.254       0.254
    XHJN       0.254       0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
```

```
* XHJN = 24" / sin(45) = 0.8621 m
*
  PATHS      25          27
    LABEL  VENT-EXH    PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0           0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       0.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
!    KFILTER  0.0
!    FGAS1JN  1.0
!    IFAN     1
!    WVFAN    8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
```

```
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS      28          29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP      8           8
    ICCJN      0           0
    IR1       15          15
    IR2       10          12
    IHORIZ     1           1
    AJN        1.0         1.0
    Z1JN       7.4676     -5.6134
    Z2JN       7.4676      3.7846
    CJN        2.8         2.8
    KFILTER    0.870       0.870
    FGAS1JN    1.0         1.0
    XLJN       1.0         1.0
    XWJN       1.0         1.0
    XHJN       1.0         1.0
  END PATHS
*
END JUNCTIONS
```

B.6 Case File: CONTLN1.dat

```
*-----------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
******************************************************************
*
*   CASE CONTLN1: STSC IN T-PLANT LONG CELL (2R), FAN OFF
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE CON2STSC1.DAT
*
******************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.       !  END TIME (Seconds)
    DTMIN       0.01        !  MIN TIMESTEP (Seconds)
    DTMAX                   !  MAX TIMESTEP (Seconds)
    0.            0.2
    200.          0.5
    500.          1.0
    1000.         3.0
    10000.       10.0
    DTPRIN     86400.       !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.       !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.       !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.       !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2       ! Keyword for plotting section
*
    PRESSURE      2    10 15                   ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10    101 102 103 106 107 108 111 112 113 114
    HS-TI        10    116 117 121 122 123 124 125 126 127 128
    HS-TI         3    131 132 133
    HS-TO         3    103 113 114
    QGAS-HSI      1    124
    HS-T  124    10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3    6  11 10                      ! N2 %
    GAS-X  OXYGEN     3    6  11 10                      ! O2 %
    GAS-X  STEAM      3    6  11 10                      ! H2O %
    GAS-X  HYDROGEN   3    6  11 10                      ! H2 %
    GAS-W            10    11 12 13 14 15 16 17 18 19 20
    GAS-W             9    21 22 24 25 26 27 28 29
    GAS-WX           10    11 12 13 14 15 16 17 18 19 20
    GAS-WX            9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other seven containers containing settler sludge
* into Cell 2R (11)
* 1 STSC:  1.6 m^3 * 590 Kg-U/m^3 * 0.08814 W/kg-U
*        =   83.2 W
* 7 STSCs: 582.4 W
*
* Oxidation (reaction) heat:
* 1 STSC: 116 W
* 7 STSCs: 7 * 116 W        = 812 W
```

```
*
* Total heat load for 7 STSCs: 1394.4 W
*
* H2 Generation Rate:
* 1 STSC   = 838 l/day
*          = 838 l/day * 1/86400 day/s * 0.07598 kg/m**3 * 1/1000 m**3/l
*          = 7.37E-7 kg/s
* 7 STSCs:   5.159E-6 kg/s
*
  SOURCES 2
    REGION 11 GASES 1  PHASE 1
      HYDROGEN
      0       50.0  5.159E-6   1394.4
      1.E9    50.0  5.159E-6   1394.4
    END REGION
*
* Decay heat from six containers of container sludge in each of four
* cells in the Hot Cell (14)
* 4 * 6 * 83.2 W =              1996.8 W
*
* Oxidation (reaction) heat:
*  1 STSC:          116 W
* 24 STSCs: 4 * 6 * 116 W      = 2784.0 W
*
* Total heat load for 5 STSCs:   4780.8 W
*
* H2 Generation Rate:
*  1 STSC   = 7.37E-7 kg/s
* 24 STSCs  = 1.77E-5 kg/s
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0       50.0    1.77E-5  4780.8
      1.E9    50.0    1.77E-5  4780.8
    END REGION
  END SOURCES
END CONTROL
*-----------------------------------------------------------------------
VOLUMES
*-----------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS         6
    LABEL        T-CELL
    VOLUME       143.08
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES           6
    STEAM         0.01
    OXYGEN        0.20
    NITROGEN      0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
```

```
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS              7          11         12          14
    SAME_AS            6           6          6           6
    LABEL          COLD-CELL     CELL-2R    CELL-2L    HOT-CELL
    VOLUME          4435.48      185.11     251.39      458.52
    SED_AREA         521.42       33.21      33.21       67.28
    ELEVATION         -0.9906     -0.9906    -1.8542     -0.9906
    TEMP_GAS         32.0        32.0       32.0        32.0
    PRESSURE          1.0E5       1.0E5      1.0E5       1.0E5
    ZTOP              6.7056      6.7056     7.5692      6.7056
  END REGIONS
*
  GASES                7          11         12          14
    SAME_AS            6           6          6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS              8
    SAME_AS            6
    LABEL             VENT
    VOLUME          2023.0
    SED_AREA         632.1
    ELEVATION         -0.9906
    TEMP_GAS         32.0
    PRESSURE          1.0E5
    ZTOP              3.2
  END REGIONS
*
  GASES                8
    SAME_AS            6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
```

```
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
  REGIONS            9
    LABEL          PTRENCH
    VOLUME           951.45
    SED_AREA         520.26
    ELEVATION          4.3434
    ZTOP               1.83
    TEMP_GAS          23.0
    PRESSURE           1.0E5
  END REGIONS
*
  GASES              9
    SAME_AS          6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS             13          16
    SAME_AS            8           8
    LABEL          PIPE-24    EXH-DUCT
    VOLUME            2.9357    115.0
    SED_AREA          6.1316     53.88
    ELEVATION         1.7526     -0.9906
    ZTOP              0.6096      2.1336
    TEMP_GAS         32.0        32.0
    PRESSURE          1.0E5       1.0E5
  END REGIONS
*
  GASES               13          16
    SAME_AS            8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"         , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS             10               15
    LABEL            CANYON          AMBIENT
    VOLUME          40818.E0           1.E9
    SED_AREA         4245.E0           1.E6
    ELEVATION           7.5438         7.5438
    TEMP_GAS           32.0           25.0
    PRESSURE            1.0E5          1.0E5
    ZTOP               14.9352         1.E3
!    ZTOP               1.E3           1.E3
  END REGIONS
*
  GASES               10               15
    STEAM              0.01            0.01
    OXYGEN             0.20            0.20
    NITROGEN           0.79            0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
```

```
*
*  OFFSET_TIMEPG       0.0
*  EXTRAPOLATION_TIMEPG    PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                 50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-----------------------------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*             process cell      process cell      cell
*             long sidewall     short sidewall    cover block
  SINKS          101               102               103
*
    LABEL        PC-LSW            PC-SSW            PC-COV
    IORIHS         0                 0                 1
    IGEOM          1                 1                 1
    IMATHS         3                 3                 3
    XRI           0.0               0.0               0.0
    XRO           1.067             1.372             1.829
    AHS          72.217            53.141            21.337
    TIINIT       32.00             32.00             32.00
    TOINIT       32.00             32.00             35.00
    IMSLAB        20                20                20
    IREGI          6                 6                10
    IREGO          0                 0                 6
    XLHS          6.7056            6.7056            3.9624
    XZHS          6.7056            6.7056            3.9624
    ZTHS          5.7150            5.7150            7.5438
    ZBHS         -0.9906           -0.9906            5.7150
  END
*
*               31 COLD CELLS
*
*             long sidewall     short sidewall    cover block
  SINKS          106               107               108
*
    LABEL        CC-LSW            CC-SSW            CC-COV
    SAME_AS       101               102               103
    AHS          2.239E3           1.647E3           6.614E2
    TIINIT       32.00             32.00             32.00
    TOINIT       32.00             32.00             32.00
    IREGI          7                 7                10
    IREGO          0                 0                 7
  END
*
*               CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
```

```
*             long sidewall      long sidewall      short sidewall     cover
*             block
  SINKS          111                114                112                113
*
    LABEL        2R-LSW             2R-2L              2R-SSW             2R-COV
    SAME_AS       101                101                102                103
    AHS           56.206             56.206             53.141             33.213
    TIINIT        35.00              35.00              32.00              32.0
    TOINIT        35.00              35.00              32.00              32.0
    IREGI         11                 11                 11                 10
    IREGO          0                 12                 0                  11
  END
*
*              CELL 2L
*
*             long sidewall                         short sidewall
*
  SINKS          116                                   117
*
    LABEL        2L-LSW                                2L-SSW
    SAME_AS       111                                   112
    IREGI         12                                    12
    IREGO          0                                     0
  END
*
*               4 HOT CELLS
*
*                  long sidewall  short sidewall     cover block
  SINKS              126            127                128
*
    LABEL             CC-LSW         CC-SSW             CC-COV
    SAME_AS           101            102                103
    AHS               288.9          212.6              85.35
    IREGI             14             14                 10
    IREGO             0              0                  14
  END
*
*               VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS          121
*
    IORIHS         0
    IGEOM          1
    IMATHS         3
    XRI            0.0
    XRO            1.52
    AHS            1405.4
    TIINIT         32.0
    TOINIT         32.0
    IMSLAB         20
    IREGI          8
    IREGO          0
    XLHS           3.20
    XZHS           3.20
    ZTHS           2.21
    ZBHS           -0.9906
  END
*
*               CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS          131               132
*
    IORIHS         0                 0
    IGEOM          1                 1
    IMATHS         3                 3
    XRI          0.0               0.0
```

```
    XRO          1.52          0.915
    AHS          4090.0        2224.7
    TIINIT       32.00         32.00
    TOINIT       32.00         35.00
    IMSLAB        20            20
    IREGI         10            10
    IREGO          0             0
    XLHS         12.0          12.0
    XZHS         12.0          12.0
    ZTHS         15.394        19.664
    ZBHS         7.5438        15.394
  END
*
*           PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*           COVER IS    8 X (35 X 20) FT**2
*
*             wall           cover
  SINKS        122            123
*
    IORIHS         0              1
    IGEOM          1              1
    IMATHS         3              3
    XRI          0.0            0.0
    XRO          1.52           1.37
    AHS          781.0          520.5
    TIINIT       32.00          32.00
    TOINIT       32.00          32.00
    IMSLAB        20             20
    IREGI          9             10
    IREGO          0              9
    XLHS         1.83           1.83
    XZHS         1.83           1.83
    ZTHS         6.1710         7.5438
    ZBHS         4.3426         6.1710
  END
*
*          24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS        124            125
*
    IORIHS       0              0
    IGEOM        0              0
    IMATHS       3              3
    XRI          0.6096         0.3048
    XRO          5.0            0.6096
    AHS          177.3          2.8727
    TIINIT       32.00          32.00
    TOINIT       32.00          32.00
    IMSLAB       30             20
    IREGI        0              13
    IREGO        0              0
    XLHS         12.0           0.6096
    XZHS         10.1           10.1
!    ZTHS        ?              ?
!    ZBHS        ?              ?
  END
*
*-------------------------------------------------------------------
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
*
  SINKS       68
!   LABEL      TOP
    IREGO      11
  END
*
* INNER CYLINDER AND STSC WALL ADJACENT TO WATER AND GAS
```

```
*
*           Layer 21
  SINKS        61
!   LABEL      WALLO-21
    IREGO      11
  END
*
*             Volume       Cumulative volume
* LAYER-13     0.03849      0.53849
*-----------------------------------------------------
* LAYER-12     0.09337      0.50000
*
*           Layer 20
  SINKS         58
    IREGO       11
  END
*           Layer 19
  SINKS         55
    IREGO       11
  END
*           Layer 18
  SINKS         52
    IREGO       11
  END
*           Layer 17
  SINKS         49
    IREGO       11
  END
*           Layer 16
  SINKS         46
    IREGO       11
  END
*           Layer 15
  SINKS         43
    IREGO       11
  END
*           Layer 14
  SINKS         40
    IREGO       11
  END
*           Layer 13
  SINKS         37
    IREGO       11
  END
*           Layer 12
  SINKS         34
    IREGO       11
  END
*           Layer 11
  SINKS         31
    IREGO       11
  END
*
*  ELLIPTICAL SECTION
*
* lower head exterior sees atmosphere in the skirt enclosure
*
*           Layer 10
  SINKS         28
    IREGO       11
  END
*           Layer 9
  SINKS         25
    IREGO       11
  END
*           Layer 8
  SINKS         22
    IREGO       11
  END
*
* wall for Layer 7 and below is considered horizontal;
```

```
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
*
*           Layer 7
  SINKS         19
    IREGO       11
  END
*           Layer 6
  SINKS         16
    IREGO       11
  END
*           Layer 5
  SINKS         13
    IREGO       11
  END
*           Layer 4
  SINKS         10
    IREGO       11
  END
*           Layer 3
  SINKS         7
    IREGO       11
  END
*
* below the inner eliptical head
*
*           Layer 2
  SINKS         4
    IREGO       11
  END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
  SINKS        96          95
!   LABEL       SKIRT       DRIP-PAN
    IREGO      11          11
  END
*
END HEAT_SINKS
*----------------------------------------------------------------------
JUNCTIONS
*----------------------------------------------------------------------
*
* Move STSC from region 6 to region 11
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
     PATHS        1            2
!       LABEL    VENT-IN       VENT-OUT
        IR1      11            1
        IR2       1           11
     END PATHS
*
* HOLES IN THE SKIRT
*
* Redirect from typical cell (6) to cell 2R (11)
*
     PATHS        4            5            6
!       LABEL   HOLE-BOT      HOLE-MID     HOLE-TOP
        IR1      11            11           3
        IR2       3            3           11
     END PATHS
*
*----------------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
```

```
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP     8
    ICCJN     0
    IR1       6
    IR2       10
    IHORIZ    1
    AJN       1.0
    Z1JN      6.7056
    Z2JN      0.0
    CJN       1.E-5
    KFILTER  382.15
    FGAS1JN   1.0
    XLJN      1.0
    XWJN      1.0
    XHJN      1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP     8           8           8           8
    IR1       10          10          11          14
    IR2       7           9           10          10
    IHORIZ    1           1           1           1
    AJN       1.0         1.0         1.0         1.0
    Z1JN      0.0         0.0         6.7056      6.7056
    Z2JN      6.7056      1.83        0.0         0.0
    CJN       1.E-5       1.E-5       1.E-5       1.E-5
```

```
    KFILTER   10.92      159.87     231.95      76.43
    FGAS1JN    1.0         1.0        1.0        1.0
    XLJN       1.0         1.0        1.0        1.0
    XWJN       1.0         1.0        1.0        1.0
    XHJN       1.0         1.0        1.0        1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
```

```
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13         14         21
    LABEL    COLD-VENT  VENT-TCELL VENT-HOT
    IJTYP    1          1          1
    ICCJN    0          0          0
    IR1      7          8          8
    IR2      8          6          14
    IHORIZ   0          0          0
    AJN      1.7735     0.05067    0.25335
    Z1JN     2.7432     3.2004     3.2004
    Z2JN     3.2004     2.7432     2.7432
    CJN      2.8        2.8        2.8
    KFILTER  0.0        0.0        0.0
    FGAS1JN  1.0        1.0        1.0
    XLJN     2.5        2.5        2.5
    XWJN     0.254      0.254      0.254
    XHJN     0.254      0.254      0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS     16
    LABEL   PTRENCH-VENT
    IJTYP   1
    ICCJN   0
    IR1     9
    IR2     8
    IHORIZ  1
    AJN     0.9121
    Z1JN    0.0
    Z2JN    3.2004
    CJN     2.8
    FGAS1JN 1.0
    XLJN    2.5
    XWJN    0.254
    XHJN    0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
```

```
*        = 5.5118 m
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*      = 0.5454 ft**2
*      = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*        = ZTOP_12 - 6'9"
*        = 7.5692 m - 2.0574 m
*        = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*      = 0.5454 ft**2
*      = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      19         20
    LABEL    C2L-PIPE  PIPE-C2R
    IJTYP     1          1
    ICCJN     0          0
    IR1      12         13
    IR2      13         11
    IHORIZ    0          0
    AJN       0.05067    0.05067
    Z1JN      5.5118     0.0
    Z2JN      0.0        5.5118
    CJN       2.8        2.8
    FGAS1JN   1.0        1.0
    XLJN      2.5        2.5
    XWJN      0.254      0.254
    XHJN      0.254      0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*        = 4'
*        = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*      = 3.1416 ft**2
*      = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
```

```
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
*
  PATHS       25          27
    LABEL   VENT-EXH     PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0 .         0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       0.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
!    KFILTER  0.0
!    FGAS1JN  1.0
!    IFAN     1
!    WVFAN    8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
```

```
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS      28         29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP    8          8
    ICCJN    0          0
    IR1      15         15
    IR2      10         12
    IHORIZ   1          1
    AJN      1.0        1.0
    Z1JN     7.4676     -5.6134
    Z2JN     7.4676      3.7846
    CJN      2.8        2.8
    KFILTER  0.870      0.870
    FGAS1JN  1.0        1.0
    XLJN     1.0        1.0
    XWJN     1.0        1.0
    XHJN     1.0        1.0
  END PATHS
*
END JUNCTIONS
```

B.7 Case File: SETTRF1.dat

```
*-----------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
*******************************************************************
*
*   CASE SETTRF1: STSC IN T-PLANT REGULAR CELL, FAN ON
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE SET1STSC1.DAT
*
*******************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.        !  END TIME (Seconds)
    DTMIN       0.01         !  MIN TIMESTEP (Seconds)
    DTMAX                    !  MAX TIMESTEP (Seconds)
    0.          0.2
    200.        0.5
    500.        1.0
    1000.       3.0
    10000.     10.0
    DTPRIN     86400.        !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.        !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.        !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.        !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC    1    ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2      ! Keyword for plotting section
*
    PRESSURE     2    10 15                 ! CANYON, AMBIENT
    GAS-T       11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI       10    101 102 103 106 107 108 111 112 113 114
    HS-TI       10    116 117 121 122 123 124 125 126 127 128
    HS-TI        3    131 132 133
    HS-TO        3    103 113 114
    QGAS-HSI     1    124
    HS-T  124   10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3   6  11 10                    ! N2 %
    GAS-X  OXYGEN     3   6  11 10                    ! O2 %
    GAS-X  STEAM      3   6  11 10                    ! H2O %
    GAS-X  HYDROGEN   3   6  11 10                    ! H2 %
    GAS-W            10    11 12 13 14 15 16 17 18 19 20
    GAS-W             9    21 22 24 25 26 27 28 29
    GAS-WX           10    11 12 13 14 15 16 17 18 19 20
    GAS-WX            9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other five containers containing settler sludge
* into T-CELL (6)
* 1 STSC                 =  96.5 W
* 5 STSCs                = 482.5 W
*
* Oxidation power 96W/STSC:
* 5 x 96 W               = 480 W
*
* Total power for 5 STSCs  = 962.5 W
```

```
*
* H2 generation rate for 1 STSC  = 7.0E-7 kg/s
* H2 generation rate for 5 STSCs = 3.5E-6 kg/s
*
* H2 released at 50C
*
  SOURCES 2
    REGION 6  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    3.5E-6    962.5
      1.E9   50.0    3.5E-6    962.5
    END REGION
*
* Decay heat from six containers containing settler sludge in each of
* four cells in the Hot Cell (14)
*  1 STSC                      =   96.5 W
* 24 STSCs                     = 2316.0 W
*
* Oxidation power 96W/STSC:
* 4 x 6 x 96 W                 = 2304.0 W
*
* Total power for 4 x 6 STSCs  = 4620.0 W
*
* H2 generation rate for 1 STSC   = 7.00E-7 kg/s
* H2 generation rate for 24 STSCs = 1.68E-5 kg/s
*
* H2 released at 50C
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.68E-5  4620.0
      1.E9   50.0    1.68E-5  4620.0
    END REGION
  END SOURCES
END CONTROL
*-------------------------------------------------------------------
VOLUMES
*-------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL        T-CELL
    VOLUME       114.63
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
```

```
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS            7           11          12          14
    SAME_AS          6            6           6           6
    LABEL        COLD-CELL     CELL-2R     CELL-2L    HOT-CELL
    VOLUME        4435.48      222.71      251.39      458.52
    SED_AREA       521.42       33.21       33.21       67.28
    ELEVATION       -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS       32.0        32.0        32.0        32.0
    PRESSURE         1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP             6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES              7           11          12          14
    SAME_AS          6            6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            8
    SAME_AS          6
    LABEL           VENT
    VOLUME        2023.0
    SED_AREA       632.1
    ELEVATION       -0.9906
    TEMP_GAS       32.0
    PRESSURE         1.0E5
    ZTOP             3.2
  END REGIONS
*
  GASES              8
    SAME_AS          6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
```

```
  REGIONS             9
    LABEL           PTRENCH
    VOLUME            951.45
    SED_AREA          520.26
    ELEVATION           4.3434
    ZTOP                1.83
    TEMP_GAS           23.0
    PRESSURE            1.0E5
  END REGIONS
*
  GASES               9
    SAME_AS           6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            13          16
    SAME_AS           8           8
    LABEL          PIPE-24    EXH-DUCT
    VOLUME            2.9357    115.0
    SED_AREA          6.1316     53.88
    ELEVATION         1.7526     -0.9906
    ZTOP              0.6096      2.1336
    TEMP_GAS         32.0        32.0
    PRESSURE          1.0E5       1.0E5
  END REGIONS
*
  GASES              13          16
    SAME_AS           8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"        , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS            10               15
    LABEL          CANYON           AMBIENT
    VOLUME       40818.E0            1.E9
    SED_AREA      4245.E0            1.E6
    ELEVATION        7.5438          7.5438
    TEMP_GAS        32.0            25.0
    PRESSURE         1.0E5           1.0E5
    ZTOP            14.9352          1.E3
!    ZTOP             1.E3            1.E3
  END REGIONS
*
  GASES              10               15
    STEAM             0.01             0.01
    OXYGEN            0.20             0.20
    NITROGEN          0.79             0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
*
*  OFFSET_TIMEPG       0.0
```

```
*  EXTRAPOLATION_TIMEPG    PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15    27.8     25.6     23.9     23.3     29.4     36.1     39.4
                   43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-----------------------------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*           process cell      process cell      cell
*           long sidewall     short sidewall    cover block
  SINKS         101              102               103
*
    LABEL       PC-LSW           PC-SSW            PC-COV
    IORIHS        0                0                 1
    IGEOM         1                1                 1
    IMATHS        3                3                 3
    XRI          0.0              0.0               0.0
    XRO          1.067            1.372             1.829
    AHS         72.217           53.141            21.337
    TIINIT      35.00            35.00             32.00
    TOINIT      35.00            35.00             35.00
    IMSLAB       20               20                20
    IREGI         6                6                10
    IREGO         0                0                 6
    XLHS        6.7056           6.7056            3.9624
    XZHS        6.7056           6.7056            3.9624
    ZTHS        5.7150           5.7150            7.5438
    ZBHS       -0.9906          -0.9906            5.7150
  END
*
*             31 COLD CELLS
*
*           long sidewall     short sidewall    cover block
  SINKS         106              107               108
*
    LABEL       CC-LSW           CC-SSW            CC-COV
    SAME_AS      101              102               103
    AHS         2.239E3          1.647E3           6.614E2
    TIINIT      32.00            32.00             32.00
    TOINIT      32.00            32.00             32.00
    IREGI         7                7                10
    IREGO         0                0                 7
  END
*
*             CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
*           long sidewall     long sidewall      short sidewall    cover
*           block
```

```
  SINKS          111           114               112               113
*
    LABEL        2R-LSW        2R-2L             2R-SSW            2R-COV
    SAME_AS       101           101               102               103
    AHS           56.206        56.206            53.141            33.213
    TIINIT        32.00         32.00             32.00             32.0
    TOINIT        32.00         32.00             32.00             32.0
    IREGI         11            11                11                10
    IREGO          0            12                0                 11
  END
*
*            CELL 2L
*
*          long sidewall                      short sidewall
*
  SINKS          116                              117
*
    LABEL        2L-LSW                           2L-SSW
    SAME_AS       111                             112
    IREGI         12                              12
    IREGO          0                               0
  END
*
*           4 HOT CELLS
*
*             long sidewall  short sidewall     cover block
  SINKS          126           127               128
*
    LABEL         CC-LSW        CC-SSW            CC-COV
    SAME_AS       101           102               103
    AHS           288.9         212.6             85.35
    IREGI         14            14                10
    IREGO         0             0                 14
  END
*
*           VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS          121
*
    IORIHS        0
    IGEOM         1
    IMATHS        3
    XRI           0.0
    XRO           1.52
    AHS           1405.4
    TIINIT        32.0
    TOINIT        32.0
    IMSLAB        20
    IREGI         8
    IREGO         0
    XLHS          3.20
    XZHS          3.20
    ZTHS          2.21
    ZBHS          -0.9906
  END
*
*           CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS          131           132
*
    IORIHS        0             0
    IGEOM         1             1
    IMATHS        3             3
    XRI           0.0           0.0
    XRO           1.52          0.915
    AHS          4090.0        2224.7
```

```
    TIINIT        32.00          32.00
    TOINIT        32.00          35.00
    IMSLAB         20             20
    IREGI          10             10
    IREGO           0              0
    XLHS          12.0           12.0
    XZHS          12.0           12.0
    ZTHS          15.394         19.664
    ZBHS          7.5438         15.394
  END
*
*            PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*            COVER IS    8 X (35 X 20) FT**2
*
*              wall            cover
  SINKS          122             123
*
    IORIHS          0              1
    IGEOM           1              1
    IMATHS          3              3
    XRI           0.0            0.0
    XRO            1.52           1.37
    AHS           781.0          520.5
    TIINIT        32.00          32.00
    TOINIT        32.00          32.00
    IMSLAB         20             20
    IREGI           9             10
    IREGO           0              9
    XLHS           1.83           1.83
    XZHS           1.83           1.83
    ZTHS          6.1710         7.5438
    ZBHS          4.3426         6.1710
  END
*
*           24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS           124            125
*
    IORIHS         0              0
    IGEOM          0              0
    IMATHS         3              3
    XRI            0.6096         0.3048
    XRO            5.0            0.6096
    AHS            177.3          2.8727
    TIINIT         32.00          32.00
    TOINIT         32.00          32.00
    IMSLAB         30             20
    IREGI          0              13
    IREGO          0              0
    XLHS           12.0           0.6096
    XZHS           10.1           10.1
!    ZTHS          ?              ?
!    ZBHS          ?              ?
  END
*
END HEAT_SINKS
*---------------------------------------------------------------------
JUNCTIONS
*---------------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
```

```
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP      8
    ICCJN      0
    IR1        6
    IR2       10
    IHORIZ     1
    AJN        1.0
    Z1JN       6.7056
    Z2JN       0.0
    CJN        1.E-5
    KFILTER  382.15
    FGAS1JN    1.0
    XLJN       1.0
    XWJN       1.0
    XHJN       1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92      159.87      231.95       76.43
    FGAS1JN    1.0         1.0         1.0         1.0
    XLJN       1.0         1.0         1.0         1.0
```

```
    XWJN        1.0          1.0          1.0          1.0
    XHJN        1.0          1.0          1.0          1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS        18
    LABEL      CANYON-C2L
    IJTYP      1
    IR1        10
    IR2        12
    IHORIZ     1
    AJN        33.21
    Z1JN       0.0
    Z2JN       9.397
    CJN        2.8
    FGAS1JN    1.0
    XLJN       8.3820
    XWJN       3.9624
    XHJN       0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
```

```
*      = 2.7271 ft**2
*      = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13          14          21
    LABEL    COLD-VENT   VENT-TCELL  VENT-HOT
    IJTYP    1           1           1
    ICCJN    0           0           0
    IR1      7           8           8
    IR2      8           6           14
    IHORIZ   0           0           0
    AJN      1.7735      0.05067     0.25335
    Z1JN     2.7432      3.2004      3.2004
    Z2JN     3.2004      2.7432      2.7432
    CJN      2.8         2.8         2.8
    KFILTER  0.0         0.0         0.0
    FGAS1JN  1.0         1.0         1.0
    XLJN     2.5         2.5         2.5
    XWJN     0.254       0.254       0.254
    XHJN     0.254       0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*      = 9.8229 ft**2
*      = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      16
    LABEL    PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN      0.9121
    Z1JN     0.0
    Z2JN     3.2004
    CJN      2.8
    FGAS1JN  1.0
    XLJN     2.5
    XWJN     0.254
    XHJN     0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*       = ZTOP_12 - 6'9"
*       = 7.5692 m - 2.0574 m
*       = 5.5118 m
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
```

```
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS       19          20
    LABEL     C2L-PIPE   PIPE-C2R
    IJTYP      1           1
    ICCJN      0           0
    IR1       12          13
    IR2       13          11
    IHORIZ     0           0
    AJN        0.05067     0.05067
    Z1JN       5.5118      0.0
    Z2JN       0.0         5.5118
    CJN        2.8         2.8
    FGAS1JN    1.0         1.0
    XLJN       2.5         2.5
    XWJN       0.254       0.254
    XHJN       0.254       0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
*
```

```
  PATHS      25          27
    LABEL  VENT-EXH    PIPE-EXH
    IJTYP    1           1
    ICCJN    0           0
    IR1      8          13
    IR2     16          16
    IHORIZ   0           0
    AJN      1.8581      0.2919
    Z1JN     0.0         0.0
    Z2JN     0.0         1.2192
    CJN      1.E-5       2.8
    KFILTER  0.0         0.0
    FGAS1JN  1.0         1.0
    XLJN     0.001       3.048
    XWJN     1.2192      0.6096
    XHJN     1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       1.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
    KFILTER   0.0
    FGAS1JN   1.0
    IFAN     1
    WVFAN     8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
```

```
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS       28          29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP      8           8
    ICCJN      0           0
    IR1       15          15
    IR2       10          12
    IHORIZ     1           1
    AJN        1.0         1.0
    Z1JN       7.4676     -5.6134
    Z2JN       7.4676      3.7846
    CJN        2.8         2.8
    KFILTER    0.870       0.870
    FGAS1JN    1.0         1.0
    XLJN       1.0         1.0
    XWJN       1.0         1.0
    XHJN       1.0         1.0
  END PATHS
*
END JUNCTIONS
```

B.8 Case File: SETTLF1.dat

```
*-----------------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
**********************************************************************
*
*   CASE SETTLF1: STSC IN T-PLANT LONG CELL (2R), FAN ON
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE SET1STSC1.DAT
*
**********************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.       !  END TIME (Seconds)
    DTMIN       0.01        !  MIN TIMESTEP (Seconds)
    DTMAX                   !  MAX TIMESTEP (Seconds)
    0.          0.2
    200.        0.5
    500.        1.0
    1000.       3.0
    10000.     10.0
    DTPRIN     86400.       !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.       !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.       !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.       !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2       ! Keyword for plotting section
*
    PRESSURE      2    10 15                    ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10    101 102 103 106 107 108 111 112 113 114
    HS-TI        10    116 117 121 122 123 124 125 126 127 128
    HS-TI         3    131 132 133
    HS-TO         3    103 113 114
    QGAS-HSI      1    124
    HS-T  124    10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3    6   11 10                       ! N2 %
    GAS-X  OXYGEN     3    6   11 10                       ! O2 %
    GAS-X  STEAM      3    6   11 10                       ! H2O %
    GAS-X  HYDROGEN   3    6   11 10                       ! H2 %
    GAS-W            10    11 12 13 14 15 16 17 18 19 20
    GAS-W             9    21 22 24 25 26 27 28 29
    GAS-WX           10    11 12 13 14 15 16 17 18 19 20
    GAS-WX            9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other seven containers containing settler sludge
* into Cell 2R (11)
* 1 STSC                   =     96.5 W
* 7 STSCs                  =    675.5 W
*
* Oxidation power 96W/STSC:
* 7 x 96 W                 =    672.0 W
*
* Total power for 7 STSCs  =   1347.5 W
```

```
*
* H2 generation rate for 1 STSC  = 7.0E-7 kg/s
* H2 generation rate for 7 STSCs = 4.9E-6 kg/s
*
* H2 released at 50C
*
  SOURCES 2
    REGION 11 GASES 1  PHASE 1
      HYDROGEN
      0      50.0    4.9E-6   1347.5
      1.E9   50.0    4.9E-6   1347.5
    END REGION
*
* Decay heat from six containers containing settler sludge in each of
* four cells in the Hot Cell (14)
*  1 STSC                        =   96.5 W
* 24 STSCs                       = 2316.0 W
*
* Oxidation power 96W/STSC:
* 4 x 6 x 96 W                   = 2304.0 W
*
* Total power for 4 x 6 STSCs  = 4620.0 W
*
* H2 generation rate for 1 STSC   = 7.00E-7 kg/s
* H2 generation rate for 24 STSCs = 1.68E-5 kg/s
*
* H2 released at 50C
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.68E-5  4620.0
      1.E9   50.0    1.68E-5  4620.0
    END REGION
  END SOURCES
END CONTROL
*---------------------------------------------------------------------
VOLUMES
*---------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL        T-CELL
    VOLUME       143.08
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
```

```
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS            7          11          12          14
    SAME_AS          6           6           6           6
    LABEL        COLD-CELL     CELL-2R     CELL-2L    HOT-CELL
    VOLUME        4435.48      185.11      251.39      458.52
    SED_AREA       521.42       33.21       33.21       67.28
    ELEVATION      -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS       32.0        32.0        32.0        32.0
    PRESSURE        1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP            6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES              7          11          12          14
    SAME_AS          6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            8
    SAME_AS          6
    LABEL           VENT
    VOLUME        2023.0
    SED_AREA       632.1
    ELEVATION      -0.9906
    TEMP_GAS       32.0
    PRESSURE        1.0E5
    ZTOP            3.2
  END REGIONS
*
  GASES              8
    SAME_AS          6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
```

```
  REGIONS             9
    LABEL          PTRENCH
    VOLUME           951.45
    SED_AREA         520.26
    ELEVATION          4.3434
    ZTOP               1.83
    TEMP_GAS          23.0
    PRESSURE           1.0E5
  END REGIONS
*
  GASES               9
    SAME_AS           6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            13          16
    SAME_AS           8           8
    LABEL          PIPE-24     EXH-DUCT
    VOLUME             2.9357    115.0
    SED_AREA           6.1316     53.88
    ELEVATION          1.7526     -0.9906
    ZTOP               0.6096      2.1336
    TEMP_GAS          32.0        32.0
    PRESSURE           1.0E5       1.0E5
  END REGIONS
*
  GASES              13          16
    SAME_AS           8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"         , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS            10                15
    LABEL           CANYON            AMBIENT
    VOLUME         40818.E0             1.E9
    SED_AREA        4245.E0             1.E6
    ELEVATION          7.5438           7.5438
    TEMP_GAS          32.0             25.0
    PRESSURE           1.0E5            1.0E5
    ZTOP              14.9352           1.E3
!    ZTOP               1.E3             1.E3
  END REGIONS
*
  GASES            . 10                15
    STEAM              0.01             0.01
    OXYGEN             0.20             0.20
    NITROGEN           0.79             0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
*
*  OFFSET_TIMEPG        0.0
```

```
*  EXTRAPOLATION_TIMEPG    PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15      0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                  50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-------------------------------------------------------------------
HEAT_SINKS
*-------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*           process cell      process cell      cell
*           long sidewall     short sidewall    cover block
  SINKS          101              102              103
*
    LABEL       PC-LSW           PC-SSW           PC-COV
    IORIHS        0                0                1
    IGEOM         1                1                1
    IMATHS        3                3                3
    XRI          0.0              0.0              0.0
    XRO          1.067            1.372            1.829
    AHS         72.217           53.141           21.337
    TIINIT      32.00            32.00            32.00
    TOINIT      32.00            32.00            35.00
    IMSLAB       20               20               20
    IREGI         6                6               10
    IREGO         0                0                6
    XLHS        6.7056           6.7056           3.9624
    XZHS        6.7056           6.7056           3.9624
    ZTHS        5.7150           5.7150           7.5438
    ZBHS       -0.9906          -0.9906           5.7150
  END
*
*             31 COLD CELLS
*
*           long sidewall     short sidewall    cover block
  SINKS          106              107              108
*
    LABEL       CC-LSW           CC-SSW           CC-COV
    SAME_AS       101              102              103
    AHS         2.239E3          1.647E3          6.614E2
    TIINIT      32.00            32.00            32.00
    TOINIT      32.00            32.00            32.00
    IREGI         7                7               10
    IREGO         0                0                7
  END
*
*             CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
*           long sidewall     long sidewall      short sidewall    cover
*           block
```

```
 SINKS          111            114              112              113
*
   LABEL         2R-LSW         2R-2L            2R-SSW           2R-COV
   SAME_AS        101            101              102              103
   AHS            56.206         56.206           53.141           33.213
   TIINIT         35.00          35.00            32.00            32.0
   TOINIT         35.00          35.00            32.00            32.0
   IREGI          11             11               11               10
   IREGO           0             12               0                11
 END
*
*            CELL 2L
*
*          long sidewall                       short sidewall
*
 SINKS          116                              117
*
   LABEL         2L-LSW                           2L-SSW
   SAME_AS        111                              112
   IREGI          12                               12
   IREGO           0                                0
 END
*
*            4 HOT CELLS
*
*               long sidewall  short sidewall     cover block
 SINKS            126            127              128
*
   LABEL          CC-LSW         CC-SSW           CC-COV
   SAME_AS        101            102              103
   AHS            288.9          212.6            85.35
   IREGI          14             14               10
   IREGO          0              0                14
 END
*
*            VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
 SINKS          121
*
   IORIHS          0
   IGEOM           1
   IMATHS          3
   XRI             0.0
   XRO             1.52
   AHS             1405.4
   TIINIT          32.0
   TOINIT          32.0
   IMSLAB          20
   IREGI           8
   IREGO           0
   XLHS            3.20
   XZHS            3.20
   ZTHS            2.21
   ZBHS            -0.9906
 END
*
*            CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
 SINKS          131            132
*
   IORIHS          0              0
   IGEOM           1              1
   IMATHS          3              3
   XRI           0.0            0.0
   XRO           1.52           0.915
   AHS          4090.0         2224.7
```

```
    TIINIT        32.00          32.00
    TOINIT        32.00          35.00
    IMSLAB         20             20
    IREGI          10             10
    IREGO           0              0
    XLHS          12.0           12.0
    XZHS          12.0           12.0
    ZTHS          15.394         19.664
    ZBHS          7.5438         15.394
  END
*
*            PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*            COVER IS    8 X (35 X 20) FT**2
*
*              wall           cover
  SINKS         122            123
*
    IORIHS          0              1
    IGEOM           1              1
    IMATHS          3              3
    XRI           0.0            0.0
    XRO           1.52           1.37
    AHS          781.0          520.5
    TIINIT        32.00          32.00
    TOINIT        32.00          32.00
    IMSLAB         20             20
    IREGI           9             10
    IREGO           0              9
    XLHS          1.83           1.83
    XZHS          1.83           1.83
    ZTHS          6.1710         7.5438
    ZBHS          4.3426         6.1710
  END
*
*           24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS           124            125
*
    IORIHS        0              0
    IGEOM         0              0
    IMATHS        3              3
    XRI           0.6096         0.3048
    XRO           5.0            0.6096
    AHS           177.3          2.8727
    TIINIT        32.00          32.00
    TOINIT        32.00          32.00
    IMSLAB        30             20
    IREGI         0              13
    IREGO         0              0
    XLHS          12.0           0.6096
    XZHS          10.1           10.1
!     ZTHS        ?              ?
!     ZBHS        ?              ?
  END
*
*-------------------------------------------------------------------
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
*
  SINKS        68
!   LABEL      TOP
    IREGO       11
  END
*
* INNER CYLINDER AND STSC WALL ADJACENT TO WATER AND GAS
*
*           Layer 21
```

```
  SINKS         61
!   LABEL       WALLO-21
    IREGO       11
  END
*
*              Volume      Cumulative volume
* LAYER-13      0.03849      0.53849
*-----------------------------------------------------
* LAYER-12      0.09337      0.50000
*
*            Layer 20
  SINKS          58
    IREGO        11
  END
*            Layer 19
  SINKS          55
    IREGO        11
  END
*            Layer 18
  SINKS          52
    IREGO        11
  END
*            Layer 17
  SINKS          49
    IREGO        11
  END
*            Layer 16
  SINKS          46
    IREGO        11
  END
*            Layer 15
  SINKS          43
    IREGO        11
  END
*            Layer 14
  SINKS          40
    IREGO        11
  END
*            Layer 13
  SINKS          37
    IREGO        11
  END
*            Layer 12
  SINKS          34
    IREGO        11
  END
*            Layer 11
  SINKS          31
    IREGO        11
  END
*
*  ELLIPTICAL SECTION
*
* lower head exterior sees atmosphere in the skirt enclosure
*
*            Layer 10
  SINKS          28
    IREGO        11
  END
*            Layer 9
  SINKS          25
    IREGO        11
  END
*            Layer 8
  SINKS          22
    IREGO        11
  END
*
* wall for Layer 7 and below is considered horizontal;
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
```

```
*
*           Layer 7
  SINKS        19
    IREGO      11
  END
*           Layer 6
  SINKS        16
    IREGO      11
  END
*           Layer 5
  SINKS        13
    IREGO      11
  END
*           Layer 4
  SINKS        10
    IREGO      11
  END
*           Layer 3
  SINKS        7
    IREGO      11
  END
*
* below the inner eliptical head
*
*           Layer 2
  SINKS        4
    IREGO      11
  END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
  SINKS        96          95
!   LABEL       SKIRT       DRIP-PAN
    IREGO      11          11
  END
*
END HEAT_SINKS
*-----------------------------------------------------------------------
JUNCTIONS
*-----------------------------------------------------------------------
*
* Move STSC from region 6 to region 11
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
     PATHS        1            2
!       LABEL    VENT-IN      VENT-OUT
        IR1      11           1
        IR2      2            11
     END PATHS
*
* HOLES IN THE SKIRT
*
* Redirect from typical cell (6) to cell 2R (11)
*
     PATHS        4            5            6
!       LABEL   HOLE-BOT     HOLE-MID     HOLE-TOP
        IR1      11           11           3
        IR2      3            3            11
     END PATHS
*
*-----------------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
```

```
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP      8
    ICCJN      0
    IR1        6
    IR2       10
    IHORIZ     1
    AJN        1.0
    Z1JN       6.7056
    Z2JN       0.0
    CJN        1.E-5
    KFILTER  382.15
    FGAS1JN    1.0
    XLJN       1.0
    XWJN       1.0
    XHJN       1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92      159.87      463.9        76.43
    FGAS1JN    1.0         1.0         1.0         1.0
```

```
    XLJN        1.0         1.0         1.0         1.0
    XWJN        1.0         1.0         1.0         1.0
    XHJN        1.0         1.0         1.0         1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
```

```
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13          14          21
    LABEL    COLD-VENT   VENT-TCELL  VENT-HOT
    IJTYP    1           1           1
    ICCJN    0           0           0
    IR1      7           8           8
    IR2      8           6           14
    IHORIZ   0           0           0
    AJN      1.7735      0.05067     0.25335
    Z1JN     2.7432      3.2004      3.2004
    Z2JN     3.2004      2.7432      2.7432
    CJN      2.8         2.8         2.8
    KFILTER  0.0         0.0         0.0
    FGAS1JN  1.0         1.0         1.0
    XLJN     2.5         2.5         2.5
    XWJN     0.254       0.254       0.254
    XHJN     0.254       0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      16
    LABEL    PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN      0.9121
    Z1JN     0.0
    Z2JN     3.2004
    CJN      2.8
    FGAS1JN  1.0
    XLJN     2.5
    XWJN     0.254
    XHJN     0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* IR2 = 13 = 24" pipe
```

```
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS       19          20
    LABEL     C2L-PIPE   PIPE-C2R
    IJTYP      1           1
    ICCJN      0           0
    IR1       12          13
    IR2       13          11
    IHORIZ     0           0
    AJN        0.05067     0.05067
    Z1JN       5.5118      0.0
    Z2JN       0.0         5.5118
    CJN        2.8         2.8
    FGAS1JN    1.0         1.0
    XLJN       2.5         2.5
    XWJN       0.254       0.254
    XHJN       0.254       0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
```

```
*
  PATHS      25          27
    LABEL  VENT-EXH    PIPE-EXH
    IJTYP    1           1
    ICCJN    0           0
    IR1      8           13
    IR2     16           16
    IHORIZ   0           0
    AJN      1.8581      0.2919
    Z1JN     0.0         0.0
    Z2JN     0.0         1.2192
    CJN      1.E-5       2.8
    KFILTER  0.0         0.0
    FGAS1JN  1.0         1.0
    XLJN     0.001       3.048
    XWJN     1.2192      0.6096
    XHJN     1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       1.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
    KFILTER   0.0
    FGAS1JN   1.0
    IFAN     1
    WVFAN     8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
```

```
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS       28          29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP     8           8
    ICCJN     0           0
    IR1      15          15
    IR2      10          12
    IHORIZ    1           1
    AJN       1.0         1.0
    Z1JN      7.4676     -5.6134
    Z2JN      7.4676      3.7846
    CJN       2.8         2.8
    KFILTER   0.870       0.870
    FGAS1JN   1.0         1.0
    XLJN      1.0         1.0
    XWJN      1.0         1.0
    XHJN      1.0         1.0
  END PATHS
*
END JUNCTIONS
```

B.9 Case File: SETTRN1.dat

```
*------------------------------------------------------------------
CONTROL    ! Major keyword group
*------------------------------------------------------------------
*
  TITLE      ! Keyword; next line is title, title can be any length
*******************************************************************
*
*   CASE SETTRN1: STSC IN T-PLANT REGULAR CELL, FAN OFF
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE SET1STSC1.DAT
*
*******************************************************************
  END TITLE
*
  TIMING
    TLAST     1728000.        !  END TIME (Seconds)
    DTMIN        0.01         !  MIN TIMESTEP (Seconds)
    DTMAX                     !  MAX TIMESTEP (Seconds)
    0.           0.2
    200.         0.5
    500.         1.0
    1000.        3.0
    10000.      10.0
    DTPRIN     86400.         !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.         !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.         !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.         !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2       ! Keyword for plotting section
*
    PRESSURE      2    10 15                    ! CANYON, AMBIENT
    GAS-T        11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI        10   101 102 103 106 107 108 111 112 113 114
    HS-TI        10   116 117 121 122 123 124 125 126 127 128
    HS-TI         3   131 132 133
    HS-TO         3   103 113 114
    QGAS-HSI      1   124
    HS-T  124    10   30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3   6  11 10                        ! N2 %
    GAS-X  OXYGEN     3   6  11 10                        ! O2 %
    GAS-X  STEAM      3   6  11 10                        ! H2O %
    GAS-X  HYDROGEN   3   6  11 10                        ! H2 %
    GAS-W            10   11 12 13 14 15 16 17 18 19 20
    GAS-W             9   21 22 24 25 26 27 28 29
    GAS-WX           10   11 12 13 14 15 16 17 18 19 20
    GAS-WX            9   21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other five containers containing settler sludge
* into T-CELL (6)
* 1 STSC                   =  96.5 W
* 5 STSCs                  = 482.5 W
*
* Oxidation power 96W/STSC:
* 5 x 96 W                 = 480 W
*
* Total power for 5 STSCs  = 962.5 W
```

```
*
* H2 generation rate for 1 STSC  = 7.0E-7 kg/s
* H2 generation rate for 5 STSCs = 3.5E-6 kg/s
*
* H2 released at 50C
*
  SOURCES 2
    REGION 6  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    3.5E-6    962.5
      1.E9   50.0    3.5E-6    962.5
    END REGION
*
* Decay heat from six containers containing settler sludge in each of
* four cells in the Hot Cell (14)
*  1 STSC                       =   96.5 W
* 24 STSCs                      = 2316.0 W
*
* Oxidation power 96W/STSC:
* 4 x 6 x 96 W                  = 2304.0 W
*
* Total power for 4 x 6 STSCs  = 4620.0 W
*
* H2 generation rate for 1 STSC   = 7.00E-7 kg/s
* H2 generation rate for 24 STSCs = 1.68E-5 kg/s
*
* H2 released at 50C
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.68E-5  4620.0
      1.E9   50.0    1.68E-5  4620.0
    END REGION
  END SOURCES
END CONTROL
*---------------------------------------------------------------------
VOLUMES
*---------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL         T-CELL
    VOLUME        114.63
    SED_AREA      16.82
    ELEVATION     -0.9906
    TEMP_GAS      35.0
    PRESSURE      1.0E5
    ZTOP          6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
```

```
* Elevation: -3.25'
*
* Cell 2R:
* Volume:     L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:     L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:     4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS            7          11          12          14
    SAME_AS          6           6           6           6
    LABEL        COLD-CELL     CELL-2R     CELL-2L    HOT-CELL
    VOLUME         4435.48      222.71      251.39      458.52
    SED_AREA        521.42       33.21       33.21       67.28
    ELEVATION        -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS        32.0        32.0        32.0        32.0
    PRESSURE          1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP              6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES              7          11          12          14
    SAME_AS          6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:     L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:      H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            8
    SAME_AS          6
    LABEL           VENT
    VOLUME         2023.0
    SED_AREA        632.1
    ELEVATION        -0.9906
    TEMP_GAS        32.0
    PRESSURE          1.0E5
    ZTOP              3.2
  END REGIONS
*
  GASES              8
    SAME_AS          6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:     L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:      H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
```

```
  REGIONS             9
    LABEL          PTRENCH
    VOLUME          951.45
    SED_AREA        520.26
    ELEVATION         4.3434
    ZTOP              1.83
    TEMP_GAS        23.0
    PRESSURE          1.0E5
  END REGIONS
*
  GASES               9
    SAME_AS           6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            13          16
    SAME_AS           8           8
    LABEL          PIPE-24    EXH-DUCT
    VOLUME            2.9357    115.0
    SED_AREA          6.1316     53.88
    ELEVATION         1.7526     -0.9906
    ZTOP              0.6096      2.1336
    TEMP_GAS         32.0        32.0
    PRESSURE          1.0E5       1.0E5
  END REGIONS
*
  GASES              13          16
    SAME_AS           8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"         , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS            10               15
    LABEL          CANYON           AMBIENT
    VOLUME         40818.E0           1.E9
    SED_AREA        4245.E0           1.E6
    ELEVATION         7.5438          7.5438
    TEMP_GAS         32.0            25.0
    PRESSURE          1.0E5           1.0E5
    ZTOP             14.9352          1.E3
!    ZTOP             1.E3            1.E3
  END REGIONS
*
  GASES              10               15
    STEAM             0.01            0.01
    OXYGEN            0.20            0.20
    NITROGEN          0.79            0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
*
*  OFFSET_TIMEPG       0.0
```

```
*  EXTRAPOLATION_TIMEPG    PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                 50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-------------------------------------------------------------------
HEAT_SINKS
*-------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*           process cell      process cell      cell
*           long sidewall     short sidewall    cover block
  SINKS          101             102               103
*
    LABEL       PC-LSW           PC-SSW            PC-COV
    IORIHS         0               0                 1
    IGEOM          1               1                 1
    IMATHS         3               3                 3
    XRI           0.0             0.0               0.0
    XRO           1.067           1.372             1.829
    AHS          72.217          53.141            21.337
    TIINIT       35.00           35.00             32.00
    TOINIT       35.00           35.00             35.00
    IMSLAB        20              20                20
    IREGI          6               6                10
    IREGO          0               0                 6
    XLHS         6.7056          6.7056            3.9624
    XZHS         6.7056          6.7056            3.9624
    ZTHS         5.7150          5.7150            7.5438
    ZBHS        -0.9906         -0.9906            5.7150
  END
*
*            31 COLD CELLS
*
*           long sidewall     short sidewall    cover block
  SINKS          106             107               108
*
    LABEL       CC-LSW           CC-SSW            CC-COV
    SAME_AS       101             102               103
    AHS          2.239E3         1.647E3           6.614E2
    TIINIT       32.00           32.00             32.00
    TOINIT       32.00           32.00             32.00
    IREGI          7               7                10
    IREGO          0               0                 7
  END
*
*            CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
*           long sidewall     long sidewall      short sidewall    cover
*           block
```

```
  SINKS          111          114             112             113
*
    LABEL        2R-LSW       2R-2L           2R-SSW          2R-COV
    SAME_AS       101         101             102             103
    AHS           56.206      56.206          53.141          33.213
    TIINIT        32.00       32.00           32.00           32.0
    TOINIT        32.00       32.00           32.00           32.0
    IREGI         11          11              11              10
    IREGO          0          12              0               11
  END
*
*            CELL 2L
*
*          long sidewall                   short sidewall
*
  SINKS          116                          117
*
    LABEL        2L-LSW                       2L-SSW
    SAME_AS       111                         112
    IREGI         12                          12
    IREGO          0                           0
  END
*
*           4 HOT CELLS
*
*              long sidewall  short sidewall     cover block
  SINKS          126            127                128
*
    LABEL         CC-LSW         CC-SSW             CC-COV
    SAME_AS       101            102                103
    AHS           288.9          212.6              85.35
    IREGI         14             14                 10
    IREGO         0              0                  14
  END
*
*           VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS          121
*
    IORIHS        0
    IGEOM         1
    IMATHS        3
    XRI           0.0
    XRO           1.52
    AHS           1405.4
    TIINIT        32.0
    TOINIT        32.0
    IMSLAB        20
    IREGI         8
    IREGO         0
    XLHS          3.20
    XZHS          3.20
    ZTHS          2.21
    ZBHS          -0.9906
  END
*
*           CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS          131            132
*
    IORIHS        0              0
    IGEOM         1              1
    IMATHS        3              3
    XRI          0.0            0.0
    XRO          1.52           0.915
    AHS          4090.0         2224.7
```

```
    TIINIT        32.00           32.00
    TOINIT        32.00           35.00
    IMSLAB         20              20
    IREGI          10              10
    IREGO           0               0
    XLHS          12.0            12.0
    XZHS          12.0            12.0
    ZTHS          15.394          19.664
    ZBHS          7.5438          15.394
  END
*
*            PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*            COVER IS    8 X (35 X 20) FT**2
*
*              wall            cover
  SINKS         122             123
*
    IORIHS          0               1
    IGEOM           1               1
    IMATHS          3               3
    XRI            0.0             0.0
    XRO            1.52            1.37
    AHS           781.0           520.5
    TIINIT        32.00           32.00
    TOINIT        32.00           32.00
    IMSLAB         20              20
    IREGI           9              10
    IREGO           0               9
    XLHS           1.83            1.83
    XZHS           1.83            1.83
    ZTHS          6.1710          7.5438
    ZBHS          4.3426          6.1710
  END
*
*           24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS         124             125
*
    IORIHS        0               0
    IGEOM         0               0
    IMATHS        3               3
    XRI           0.6096          0.3048
    XRO           5.0             0.6096
    AHS           177.3           2.8727
    TIINIT        32.00           32.00
    TOINIT        32.00           32.00
    IMSLAB        30              20
    IREGI         0               13
    IREGO         0               0
    XLHS          12.0            0.6096
    XZHS          10.1            10.1
!    ZTHS         ?               ?
!    ZBHS         ?               ?
  END
*
END HEAT_SINKS
*-----------------------------------------------------------------
JUNCTIONS
*-----------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
```

```
* Z2JN = Canyon floor = 0.0 m
*
  PATHS       11
    LABEL     TCELL-GAP
    IJTYP      8
    ICCJN      0
    IR1        6
    IR2       10
    IHORIZ     1
    AJN        1.0
    Z1JN       6.7056
    Z2JN       0.0
    CJN        1.E-5
    KFILTER  382.15
    FGAS1JN    1.0
    XLJN       1.0
    XWJN       1.0
    XHJN       1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92      159.87      231.95       76.43
    FGAS1JN    1.0         1.0         1.0         1.0
    XLJN       1.0         1.0         1.0         1.0
```

```
    XWJN        1.0         1.0         1.0         1.0
    XHJN        1.0         1.0         1.0         1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
* AJN = 5 * pi/4 * (D**2)
```

```
*      = 2.7271 ft**2
*      = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13          14          21
    LABEL    COLD-VENT   VENT-TCELL  VENT-HOT
    IJTYP    1           1           1
    ICCJN    0           0           0
    IR1      7           8           8
    IR2      8           6           14
    IHORIZ   0           0           0
    AJN      1.7735      0.05067     0.25335
    Z1JN     2.7432      3.2004      3.2004
    Z2JN     3.2004      2.7432      2.7432
    CJN      2.8         2.8         2.8
    KFILTER  0.0         0.0         0.0
    FGAS1JN  1.0         1.0         1.0
    XLJN     2.5         2.5         2.5
    XWJN     0.254       0.254       0.254
    XHJN     0.254       0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*      = 9.8229 ft**2
*      = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      16
    LABEL    PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN      0.9121
    Z1JN     0.0
    Z2JN     3.2004
    CJN      2.8
    FGAS1JN 1.0
    XLJN     2.5
    XWJN     0.254
    XHJN     0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*       = ZTOP_12 - 6'9"
*       = 7.5692 m - 2.0574 m
*       = 5.5118 m
* IR2 = 13 = 24" pipe
* Z2JN = 0 m
```

```
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS       19          20
    LABEL     C2L-PIPE   PIPE-C2R
    IJTYP      1           1
    ICCJN      0           0
    IR1       12          13
    IR2       13          11
    IHORIZ     0           0
    AJN        0.05067     0.05067
    Z1JN       5.5118      0.0
    Z2JN       0.0         5.5118
    CJN        2.8         2.8
    FGAS1JN    1.0         1.0
    XLJN       2.5         2.5
    XWJN       0.254       0.254
    XHJN       0.254       0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
*
```

```
  PATHS      25          27
    LABEL  VENT-EXH    PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0           0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       0.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
!    KFILTER  0.0
!    FGAS1JN  1.0
!    IFAN     1
!    WVFAN    8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1  = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2  = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
```

```
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS       28          29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP     8           8
    ICCJN     0           0
    IR1       15          15
    IR2       10          12
    IHORIZ    1           1
    AJN       1.0         1.0
    Z1JN      7.4676     -5.6134
    Z2JN      7.4676      3.7846
    CJN       2.8         2.8
    KFILTER   0.870       0.870
    FGAS1JN   1.0         1.0
    XLJN      1.0         1.0
    XWJN      1.0         1.0
    XHJN      1.0         1.0
  END PATHS
*
END JUNCTIONS
```

B.10 Case File: SETTLN1.dat

```
*-----------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------
*
  TITLE     ! Keyword; next line is title, title can be any length
*****************************************************************
*
*   CASE SETTLN1: STSC IN T-PLANT LONG CELL (2R), FAN OFF
*      COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!
*
*      ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL
*      THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL
*      T-CELL HAS 6 FT THICK COVER BLOCK
*      TO BE RUN WITH BASE FILE SET1STSC1.DAT
*
*****************************************************************
  END TITLE
*
  TIMING
    TLAST    1728000.        !  END TIME (Seconds)
    DTMIN       0.01         !  MIN TIMESTEP (Seconds)
    DTMAX                    !  MAX TIMESTEP (Seconds)
    0.          0.2
    200.        0.5
    500.        1.0
    1000.       3.0
    10000.     10.0
    DTPRIN     86400.        !  PRINT INTERVAL (Seconds)
    PLTMIN      1000.        !  MIN PLOT INTERVAL (Seconds)
    PLTMAX     10000.        !  MAX INTERVAL WITHOUT PLOT (Seconds)
    DTRST      86400.        !  RESTART INTERVAL (Seconds)
  END TIMING
*
  ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
    ISRC     1     ! User-defined sources
  END ACTIVE MODELS
*
  PLOT 2       ! Keyword for plotting section
*
    PRESSURE     2    10 15                   ! CANYON, AMBIENT
    GAS-T       11     6   7   8   9  10  11  12  13  14  15  16
    HS-TI       10    101 102 103 106 107 108 111 112 113 114
    HS-TI       10    116 117 121 122 123 124 125 126 127 128
    HS-TI        3    131 132 133
    HS-TO        3    103 113 114
    QGAS-HSI     1    124
    HS-T  124   10    30 29 28 27 26 25 24 23 22 21
    GAS-X  NITROGEN   3   6  11 10                    ! N2 %
    GAS-X  OXYGEN     3   6  11 10                    ! O2 %
    GAS-X  STEAM      3   6  11 10                    ! H2O %
    GAS-X  HYDROGEN   3   6  11 10                    ! H2 %
    GAS-W            10    11 12 13 14 15 16 17 18 19 20
    GAS-W             9    21 22 24 25 26 27 28 29
    GAS-WX           10    11 12 13 14 15 16 17 18 19 20
    GAS-WX            9    21 22 24 25 26 27 28 29
  END PLOT
*
* Heat load from other STSCs in cells
*
* Decay heat from other seven containers containing settler sludge
* into Cell 2R (11)
* 1 STSC                =     96.5 W
* 7 STSCs               =    675.5 W
*
* Oxidation power 96W/STSC:
* 7 x 96 W              =    672.0 W
*
* Total power for 7 STSCs  =  1347.5 W
```

```
*
* H2 generation rate for 1 STSC  = 7.0E-7 kg/s
* H2 generation rate for 7 STSCs = 4.9E-6 kg/s
*
* H2 released at 50C
*
  SOURCES 2
    REGION 11 GASES 1  PHASE 1
      HYDROGEN
      0      50.0    4.9E-6   1347.5
      1.E9   50.0    4.9E-6   1347.5
    END REGION
*
* Decay heat from six containers containing settler sludge in each of
* four cells in the Hot Cell (14)
*  1 STSC                      =   96.5 W
* 24 STSCs                     = 2316.0 W
*
* Oxidation power 96W/STSC:
* 4 x 6 x 96 W                 = 2304.0 W
*
* Total power for 4 x 6 STSCs  = 4620.0 W
*
* H2 generation rate for 1 STSC   = 7.00E-7 kg/s
* H2 generation rate for 24 STSCs = 1.68E-5 kg/s
*
* H2 released at 50C
*
    REGION 14  GASES 1  PHASE 1
      HYDROGEN
      0      50.0    1.68E-5  4620.0
      1.E9   50.0    1.68E-5  4620.0
    END REGION
  END SOURCES
END CONTROL
*-------------------------------------------------------------------
VOLUMES
*-------------------------------------------------------------------
*
* Cells
*
* ELEVATION OF T-PLANT CELL = -1"-38" = -0.9906M
* ELEVATION OF TOP OF COVER BLOCKS = -38"+12X28" = 298"(7.5692M)
* ELEVATION OF BOTTOM OF COVER BLOCKS = -38"+12X22" = 226"(5.7404M)
* T-CELL DIMENSION, 13'(3.9624M) BY 17'8"(5.3848M) BY 22'(6.7056M)
* ASSUME 1 M^3 FOR OTHER STRUCTURES
* T-CELL VOLUME = 3.9624X5.3848X6.7056 - 6X2.5941XPI(1.4986)^2/4 - 1.0
*               = 143.08 - 27.45 - 1.0 = 114.63 M^3
* Elevation: -3'3" = -3.25' = -0.9906 m
*
  REGIONS          6
    LABEL        T-CELL
    VOLUME       143.08
    SED_AREA     16.82
    ELEVATION    -0.9906
    TEMP_GAS     35.0
    PRESSURE     1.0E5
    ZTOP         6.7056
  END REGIONS
*
  GASES            6
    STEAM          0.01
    OXYGEN         0.20
    NITROGEN       0.79
  END GASES
*
* Cold Cell:
* The "cold cell" is a combination of 31 standard process cells
* with no STSCs or internals.
* Volume: 31 * 143.08 m**3   = 4435.48 m**3
* Sed. Area: 31 * 16.82 m**2 =  521.42 m**2
```

```
* Elevation: -3.25'
*
* Cell 2R:
* Volume:    L=27'6" W=13' H=22' V = 7865 ft**3 = 222.71 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Elevation: -3.25'
*
* Cell 2L:
* Cell 2L is slightly deeper than 2R due to train tracks, plus has no cover
* blocks. This adds another 6' of height to the cell
* Volume:    L=27'6" W=13' H=30'10" V = 11022.92 ft**3 = 312.13 m**3
* Sed. Area: L=27'6" W=13' A = 357.5 ft**2 = 33.21 m**2
* Z-top: H=30'10" = 9.398m
* Elevation:  -3'3" + 28' - 30'10" = -6'1" = -1.8542 m
*
* Hot Cell:
* The "hot cell" is a combination of 4 standard process cells.
* including STSCs and internals.
* Volume:    4 * 114.63 m**3 = 458.52 m**3
* Sed. Area: 4 * 16.82 m**2  =  67.28 m**2
* Elevation: -3.25'
*
  REGIONS             7          11          12          14
    SAME_AS           6           6           6           6
    LABEL          COLD-CELL    CELL-2R     CELL-2L    HOT-CELL
    VOLUME          4435.48     185.11      251.39      458.52
    SED_AREA         521.42      33.21       33.21       67.28
    ELEVATION        -0.9906     -0.9906     -1.8542     -0.9906
    TEMP_GAS         32.0        32.0        32.0        32.0
    PRESSURE          1.0E5       1.0E5       1.0E5       1.0E5
    ZTOP              6.7056      6.7056      7.5692      6.7056
  END REGIONS
*
  GASES               7          11          12          14
    SAME_AS           6           6           6           6
  END GASES
*
* VENTS AND DUCTING
*
* Vent duct (runs along the face of 40 standard cells, each 18' wide):
* Volume:    L=36 * 18' W=10.5' H=10.5' V = 71442 ft**3 = 2023.0 m**3
* Sed. Area: L=36 * 18' W=10.5' A = 6804 ft**2 = 632.1 m**2
* Z-top:     H=10.5' = 3.2 m
* Elevation: -3.25' = -0.9906 m
*
  REGIONS             8
    SAME_AS           6
    LABEL            VENT
    VOLUME          2023.0
    SED_AREA         632.1
    ELEVATION        -0.9906
    TEMP_GAS         32.0
    PRESSURE          1.0E5
    ZTOP              3.2
  END REGIONS
*
  GASES               8
    SAME_AS           6
  END GASES
*
* Pipe Trench:
* Sed. Area: L=(35 X 20') W=8' A = 5600 ft**2 = 520.26 m**2
* Volume:    L=(35 X 20') W=8' H=6' V = 33600 ft**3 = 951.45 m**3
* Z-top:     H=6' = 1.83 m
* Elevation: 10.5' below canyon deck (14.25' = 28' - 3.25' - 10.5' = )
* STSC bottom elevation: 0'
* T-Cell floor elevation: -3.25'
* Canyon deck elevation: 28' - 3.25' = 24.75'
* Pipe trench cover block depth: 4.5'
* Pipe trench floor elevation: 24.75' - 4.5' - 6' = 14.25' = 4.3434 m
*
```

```
  REGIONS             9
    LABEL           PTRENCH
    VOLUME            951.45
    SED_AREA          520.26
    ELEVATION           4.3434
    ZTOP                1.83
    TEMP_GAS          23.0
    PRESSURE            1.0E5
  END REGIONS
*
  GASES               9
    SAME_AS           6
  END GASES
*
* 24" Pipe:
* Sed. Area: D=2' L=7' + 2 * 13' A = D * L = 66 ft**2 = 6.1316 m**2
* Volume: D=2' L=7' + 2 * 13' V = 103.67 ft**3 = 2.9357 m**3
* Z-top: D=2' = 0.6096 m
* Elevation: -3.25' + 28' - 19' = 5.75' = 1.7526 m
*
* Exhaust duct:
* Sed. Area: L=145' W=4' A = 580 ft**2 = 53.88 m**2
* Volume:    L=145' W=4' H=7' V = 4060 ft**2 = 115.0 m**2
* Z-top:     H=7'
* Elevation: -3.25' = -0.9906 m
*
  REGIONS            13          16
    SAME_AS           8           8
    LABEL          PIPE-24     EXH-DUCT
    VOLUME            2.9357    115.0
    SED_AREA          6.1316     53.88
    ELEVATION         1.7526     -0.9906
    ZTOP              0.6096      2.1336
    TEMP_GAS         32.0        32.0
    PRESSURE          1.0E5       1.0E5
  END REGIONS
*
  GASES              13          16
    SAME_AS           8           8
  END GASES
*
* ATMOSPHERES
*
* Canyon Length = 43' + 680' + 38.5' = 761.5 ft = 232.1 m
* Lower H = 25'9" = 7.85m, W = 37'2", AX1 = 88.96 m**2
* Upper H = 14'   = 4.27m, W = 60'2", AX2 = 78.30 m**2
* Crane H =  9'3"        , W = 10'  , AX3 =  8.60 m**2
* Canyon total height = 25'9" + 14' + 9'3" = 49' = 14.9352m
* Volume = 232.1 x (88.96+78.30+8.60) = 40,818 m**3
* Sed area 232.1 m x 60ft = 4245 m**2
*
  REGIONS            10              15
    LABEL          CANYON          AMBIENT
    VOLUME         40818.E0          1.E9
    SED_AREA        4245.E0          1.E6
    ELEVATION         7.5438         7.5438
    TEMP_GAS         32.0           25.0
    PRESSURE          1.0E5          1.0E5
    ZTOP             14.9352         1.E3
!    ZTOP              1.E3           1.E3
  END REGIONS
*
  GASES              10              15
    STEAM             0.01           0.01
    OXYGEN            0.20           0.20
    NITROGEN          0.79           0.79
  END GASES
*
* CONTROL BOUNDARY PRESSURE
*
*  OFFSET_TIMEPG       0.0
```

```
*  EXTRAPOLATION_TIMEPG     PERIOD  !repeat the diurnal cycle
*    TIMEP  15   0.0   21600.   43200.   64800.   86400.
*    PRFIX  15   1.0E5  1.005E5 1.0E5    9.95E4   1.0E5

  OFFSET_TIMETG 28800
  EXTRAPOLATION_TIMETG PERIOD
      TIMETG 15     0.    7200.0 14400.0 21600.0 28800.0 36000.0 43200.0
                50400.0 57600.0 64800.0 72000.0 79200.0 86400.0
      TGFIX  15     27.8     25.6     23.9     23.3     29.4     36.1     39.4
                    43.9     46.1     45.0     37.8     31.7     27.8
END VOLUME
*
*-------------------------------------------------------------------
HEAT_SINKS
*-------------------------------------------------------------------
*
*  CELL CONCRETE HEAT SINKS
*
*  IGNORE HEAT TRANSFER TO FLOOR
*
* thickness of sidewall = 1.067 (3.5')
* thickness of front/back wall = 1.372 (4.5')
* thickness of cover block = 1.829 (6')
* one-sided area of long sidewall = 2 X 5.3848(17'8")*6.7056(22') = 72.217
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 5.3848(17'8")*3.9624(13') = 21.337
*
*            process cell      process cell      cell
*            long sidewall     short sidewall    cover block
  SINKS          101              102               103
*
    LABEL       PC-LSW           PC-SSW            PC-COV
    IORIHS        0                0                 1
    IGEOM         1                1                 1
    IMATHS        3                3                 3
    XRI          0.0              0.0               0.0
    XRO          1.067            1.372             1.829
    AHS          72.217           53.141            21.337
    TIINIT       32.00            32.00             32.00
    TOINIT       32.00            32.00             35.00
    IMSLAB        20               20                20
    IREGI         6                6                 10
    IREGO         0                0                 6
    XLHS         6.7056           6.7056            3.9624
    XZHS         6.7056           6.7056            3.9624
    ZTHS         5.7150           5.7150            7.5438
    ZBHS        -0.9906          -0.9906            5.7150
  END
*
*             31 COLD CELLS
*
*            long sidewall     short sidewall    cover block
  SINKS          106              107               108
*
    LABEL       CC-LSW           CC-SSW            CC-COV
    SAME_AS      101              102               103
    AHS          2.239E3          1.647E3           6.614E2
    TIINIT       32.00            32.00             32.00
    TOINIT       32.00            32.00             32.00
    IREGI         7                7                 10
    IREGO         0                0                 7
  END
*
*             CELL 2R
*
* one-sided area of long sidewall = 1 X 8.3820(27'6")*6.7056(22') = 56.206
* one-sided area of short sidewall = 2 X 3.9624(13')*6.7056(22') = 53.141
* one-sided area of cover block = 8.3820(27'6")*3.9624(13') = 33.213
*
*            long sidewall     long sidewall      short sidewall    cover
*            block
```

```
  SINKS          111           114              112              113
*
   LABEL          2R-LSW        2R-2L            2R-SSW           2R-COV
   SAME_AS         101          101              102              103
   AHS             56.206       56.206           53.141           33.213
   TIINIT          35.00        35.00            32.00            32.0
   TOINIT          35.00        35.00            32.00            32.0
   IREGI           11           11               11               10
   IREGO            0           12               0                11
  END
*
*            CELL 2L
*
*          long sidewall                       short sidewall
*
  SINKS          116                             117
*
   LABEL          2L-LSW                          2L-SSW
   SAME_AS         111                            112
   IREGI           12                             12
   IREGO            0                              0
  END
*
*           4 HOT CELLS
*
*              long sidewall  short sidewall     cover block
  SINKS          126           127               128
*
   LABEL           CC-LSW        CC-SSW            CC-COV
   SAME_AS         101           102               103
   AHS             288.9         212.6             85.35
   IREGI           14            14                10
   IREGO           0             0                 14
  END
*
*           VENT DUCT
*
* 2 x 10.5 x (18 X 40) FT**2
*
  SINKS          121
*
   IORIHS          0
   IGEOM           1
   IMATHS          3
   XRI             0.0
   XRO             1.52
   AHS             1405.4
   TIINIT          32.0
   TOINIT          32.0
   IMSLAB          20
   IREGI           8
   IREGO           0
   XLHS            3.20
   XZHS            3.20
   ZTHS            2.21
   ZBHS            -0.9906
  END
*
*           CANYON
*
* lower canyon walls: 5 ft thick, 7.85m high, 260.5 m long, x2
* upper canyon walls: 3 ft thick, 4.27m high, x2
*
  SINKS          131           132
*
   IORIHS          0             0
   IGEOM           1             1
   IMATHS          3             3
   XRI            0.0           0.0
   XRO            1.52          0.915
   AHS           4090.0        2224.7
```

```
    TIINIT        32.00         32.00
    TOINIT        32.00         35.00
    IMSLAB         20            20
    IREGI          10            10
    IREGO           0             0
    XLHS          12.0          12.0
    XZHS          12.0          12.0
    ZTHS          15.394        19.664
    ZBHS          7.5438        15.394
  END
*
*           PIPE TRENCH
*
* PIPE TRENCH WALL IS 2 X 6 X (35 X 20) FT**2
*           COVER IS    8 X (35 X 20) FT**2
*
*              wall           cover
  SINKS         122            123
*
    IORIHS          0             1
    IGEOM           1             1
    IMATHS          3             3
    XRI           0.0           0.0
    XRO           1.52          1.37
    AHS          781.0         520.5
    TIINIT        32.00         32.00
    TOINIT        32.00         32.00
    IMSLAB         20            20
    IREGI           9            10
    IREGO           0             9
    XLHS          1.83          1.83
    XZHS          1.83          1.83
    ZTHS          6.1710        7.5438
    ZBHS          4.3426        6.1710
  END
*
*          24 INCH PIPE
*
* length = 2.1336 + 2*3.9624 = 10.0584
*
  SINKS          124            125
*
    IORIHS         0             0
    IGEOM          0             0
    IMATHS         3             3
    XRI            0.6096        0.3048
    XRO            5.0           0.6096
    AHS            177.3         2.8727
    TIINIT         32.00         32.00
    TOINIT         32.00         32.00
    IMSLAB         30            20
    IREGI          0             13
    IREGO          0             0
    XLHS           12.0          0.6096
    XZHS           10.1          10.1
!    ZTHS          ?             ?
!    ZBHS          ?             ?
  END
*
*-------------------------------------------------------------------
*
* SET ZTHS TO REGION 1 TOP ELEVATION, 2.43327 M
*
  SINKS       68
!   LABEL      TOP
    IREGO      11
  END
*
* INNER CYLINDER AND STSC WALL ADJACENT TO WATER AND GAS
*
*         Layer 21
```

```
  SINKS         61
!   LABEL       WALLO-21
    IREGO       11
  END
*
*              Volume      Cumulative volume
* LAYER-13      0.03849      0.53849
*-------------------------------------------------------
* LAYER-12      0.09337      0.50000
*
*             Layer 20
  SINKS          58
    IREGO        11
  END
*             Layer 19
  SINKS          55
    IREGO        11
  END
*             Layer 18
  SINKS          52
    IREGO        11
  END
*             Layer 17
  SINKS          49
    IREGO        11
  END
*             Layer 16
  SINKS          46
    IREGO        11
  END
*             Layer 15
  SINKS          43
    IREGO        11
  END
*             Layer 14
  SINKS          40
    IREGO        11
  END
*             Layer 13
  SINKS          37
    IREGO        11
  END
*             Layer 12
  SINKS          34
    IREGO        11
  END
*             Layer 11
  SINKS          31
    IREGO        11
  END
*
*  ELLIPTICAL SECTION
*
* lower head exterior sees atmosphere in the skirt enclosure
*
*             Layer 10
  SINKS          28
    IREGO        11
  END
*             Layer 9
  SINKS          25
    IREGO        11
  END
*             Layer 8
  SINKS          22
    IREGO        11
  END
*
* wall for Layer 7 and below is considered horizontal;
* heat transfer due to laminar boundary layer underside
* of a hot plate is modeled in FATE
```

```
*
*           Layer 7
  SINKS         19
    IREGO       11
  END
*           Layer 6
  SINKS         16
    IREGO       11
  END
*           Layer 5
  SINKS         13
    IREGO       11
  END
*           Layer 4
  SINKS         10
    IREGO       11
  END
*           Layer 3
  SINKS         7
    IREGO       11
  END
*
* below the inner eliptical head
*
*           Layer 2
  SINKS         4
    IREGO       11
  END
*
* SKIRT AND DRIP PAN
*
* MODEL DRIP-PAN AS VERTICAL HS TO ALLOW CONVECTIVE HT TO CELL
  SINKS         96          95
!   LABEL       SKIRT       DRIP-PAN
    IREGO      11          11
  END
*
END HEAT_SINKS
*-----------------------------------------------------------------
JUNCTIONS
*-----------------------------------------------------------------
*
* Move STSC from region 6 to region 11
*
* 2" INLET VENT
* 4" OUTLET VENT WITH 2 FOOT (0.6096 M) CHIMNEY
*
     PATHS        1             2
!       LABEL     VENT-IN       VENT-OUT
        IR1       11             1
        IR2        2            11
     END PATHS
*
* HOLES IN THE SKIRT
*
* Redirect from typical cell (6) to cell 2R (11)
*
     PATHS        4             5             6
!       LABEL   HOLE-BOT      HOLE-MID      HOLE-TOP
        IR1       11            11             3
        IR2        3             3            11
     END PATHS
*
*-----------------------------------------------------------------
*
* Canyon to cells & pipe trench through cover block gaps
*
* Path 11: Process cell to canyon via gap
* [References needed for CJN, KFILTER]
* IR1 = 6 = T-Cell
* Z1JN = Cell height = ZTOP = 6.7056 m
```

```
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
  PATHS        11
    LABEL      TCELL-GAP
    IJTYP       8
    ICCJN       0
    IR1         6
    IR2        10
    IHORIZ      1
    AJN         1.0
    Z1JN        6.7056
    Z2JN        0.0
    CJN         1.E-5
    KFILTER   382.15
    FGAS1JN     1.0
    XLJN        1.0
    XWJN        1.0
    XHJN        1.0
  END PATHS
*
* Path 12: Canyon to cold cells via cover block gaps
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 7 = Cold cells
* Z2JN = Cell height = ZTOP = 6.7056 m
* KFILTER = 1 / ( sum[i=1.35] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 35
*         = 382.15 / 35 = 10.92
*
* Path 15: Canyon to pipe trench via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 9 = Pipe trench
* Z2JN = Trench height = ZTOP = 1.83 m
* KFILTER = (Kwidth * Klength) / (2 * (Kwidth + Klength))
*         = (389.7 * 1781.1) / (2 * (389.7 + 1781.1))
*         = 159.87
*
* Path 17: Cell 2R to canyon via cover block gaps
* [References needed for CJN, KFILTER]
* IR1 = 11 = Cell 2R
* Z1JN = Cell 2R height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
*
* Path 22: Hot cells to canyon via cover block gaps
* [References needed for CJN]
* IR1 = 14 = Hot cells
* Z1JN = Cell height = ZTOP = 6.7056 m
* IR2 = 10 = Canyon
* Z2JN = Canyon floor = 0.0 m
* KFILTER = 1 / ( sum[i=1.5] (1 / KFILTER_tcell) )
*         = KFILTER_tcell / 5
*         = 382.15 / 5 = 76.43
*
  PATHS       12          15          17          22
    SAME_AS   11          11          11          11
    LABEL     GAP-COLD    GAP-PIPE    C2R-GAP     HOT-GAP
    IJTYP      8           8           8           8
    IR1       10          10          11          14
    IR2        7           9          10          10
    IHORIZ     1           1           1           1
    AJN        1.0         1.0         1.0         1.0
    Z1JN       0.0         0.0         6.7056      6.7056
    Z2JN       6.7056      1.83        0.0         0.0
    CJN        1.E-5       1.E-5       1.E-5       1.E-5
    KFILTER   10.92      159.87      231.95       76.43
    FGAS1JN    1.0         1.0         1.0         1.0
```

```
    XLJN        1.0         1.0         1.0         1.0
    XWJN        1.0         1.0         1.0         1.0
    XHJN        1.0         1.0         1.0         1.0
  END PATHS
*
* Path 18: Canyon to Cell 2L
* [References needed for CJN]
* IR1 = 10 = Canyon
* Z1JN = Canyon floor = 0.0 m
* IR2 = 12 = Cell 2L
* Z2JN = Full cell 2L height = 30'10" = 9.397 m
* AJN = SED_AREA = 33.21 m**2
* XLJN = L = 27.5' = 8.3820 m
* XWJN = W = 13'   = 3.9624 m
* XHJN = 0.001 m = thin
*
  PATHS       18
    LABEL     CANYON-C2L
    IJTYP     1
    IR1       10
    IR2       12
    IHORIZ    1
    AJN       33.21
    Z1JN      0.0
    Z2JN      9.397
    CJN       2.8
    FGAS1JN   1.0
    XLJN      8.3820
    XWJN      3.9624
    XHJN      0.001
  END PATHS
*
* Cells to ventilation duct
*
* Path 13: Cold cells to ventilation duct via 10"-dia pipe.
* [Reference needed for CJN]
* IR1 = 7 = Cold cells
* Z1JN = 9' = 2.7432 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 35 pipes for 35 cold cells:
* AJN = 35 * pi/4 * (D**2)
*     = 19.1 ft**2
*     = 1.7735 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 14: Ventilation duct to process cell via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 6 = T cell
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 21: Ventilation duct to hot cells via 10"-dia pipe.
* [References needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = top of duct = ZTOP = 10.5' = 3.2004 m
* IR2 = 14 = Hot cells
* Z2JN = 9' = 2.7432 m
* CJN = (1/0.6)**2 = 2.8
* Consider 5 pipes for 5 hot cells:
```

```
* AJN = 5 * pi/4 * (D**2)
*     = 2.7271 ft**2
*     = 0.25335 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      13          14          21
    LABEL    COLD-VENT   VENT-TCELL  VENT-HOT
    IJTYP    1           1           1
    ICCJN    0           0           0
    IR1      7           8           8
    IR2      8           6           14
    IHORIZ   0           0           0
    AJN      1.7735      0.05067     0.25335
    Z1JN     2.7432      3.2004      3.2004
    Z2JN     3.2004      2.7432      2.7432
    CJN      2.8         2.8         2.8
    KFILTER  0.0         0.0         0.0
    FGAS1JN  1.0         1.0         1.0
    XLJN     2.5         2.5         2.5
    XWJN     0.254       0.254       0.254
    XHJN     0.254       0.254       0.254
  END PATHS
*
*? Single cell pair K=160; divide by 17.5
*
* Pipe trench to ventilation duct
*
* Path 16: Pipe trench to ventilation duct via 18 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 9 = Pipe trench
* Z1JN = Pipe trench floor = 0 m
* IR2 = 8 = Ventilation duct
* Z2JN = top of duct = ZTOP = 10.5' = 3.2004 m
* CJN = (1/0.6)**2 = 2.8
* Consider 18 pipes for 18 cold cells:
* AJN = 18 * pi/4 * (D**2)
*     = 9.8229 ft**2
*     = 0.9121 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      16
    LABEL    PTRENCH-VENT
    IJTYP    1
    ICCJN    0
    IR1      9
    IR2      8
    IHORIZ   1
    AJN      0.9121
    Z1JN     0.0
    Z2JN     3.2004
    CJN      2.8
    FGAS1JN  1.0
    XLJN     2.5
    XWJN     0.254
    XHJN     0.254
  END PATHS
*
* Long cells to 24" pipe
*
* Path 19: Cell 2L to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 12 = Cell 2L
* Z1JN = 6'9" below canyon deck (note: 5'8" is at cover block level)
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* IR2 = 13 = 24" pipe
```

```
* Z2JN = 0 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
* Path 20: Cell 2R to 24" vent pipe via 10"-dia pipes.
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 11 = Cell 2R
* Z2JN = 6'9" below canyon deck
*      = ZTOP_12 - 6'9"
*      = 7.5692 m - 2.0574 m
*      = 5.5118 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 0.5454 ft**2
*     = 0.05067 m**2
* XLJN = 10' = 2.5 m
* XWJN = 10" = 0.254 m
* XHJN = 10" = 0.254 m
*
  PATHS      19         20
    LABEL    C2L-PIPE  PIPE-C2R
    IJTYP     1          1
    ICCJN     0          0
    IR1      12         13
    IR2      13         11
    IHORIZ    0          0
    AJN       0.05067    0.05067
    Z1JN      5.5118     0.0
    Z2JN      0.0        5.5118
    CJN       2.8        2.8
    FGAS1JN   1.0        1.0
    XLJN      2.5        2.5
    XWJN      0.254      0.254
    XHJN      0.254      0.254
  END PATHS
*
* 24" Pipe and vent duct to exhaust duct
*
* Path 25: Ventilation duct to exhaust duct
* [Reference needed for CJN]
* IR1 = 8 = Ventilation duct
* Z1JN = Vent duct floor = 0.0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Exhaust duct floor = 0.0 m
* AJN = 5' * 4' = 20.0 ft**2 = 1.8581 m**2
* XLJN = thin = 0.001 m
* XWJN = 4' = 1.2192 m (est.)
* XHJN = 5' = 1.5240 m
*
* Path 27: 24" vent pipe to exhaust duct
* [Reference needed for CJN]
* IR1 = 13 = 24" pipe
* Z1JN = 0 m
* IR2 = 16 = Exhaust duct
* Z2JN = Vent duct floor + 4'
*      = 4'
*      = 1.2192 m
* CJN = (1/0.6)**2 = 2.8
* AJN = pi/4 * (D**2)
*     = 3.1416 ft**2
*     = 0.2919 m**2
* XLJN = 10' = 3.048 m (est.)
* XWJN = 24" = 0.6096 m
* XHJN = 24" / sin(45) = 0.8621 m
```

```
*
  PATHS       25          27
    LABEL   VENT-EXH    PIPE-EXH
    IJTYP     1           1
    ICCJN     0           0
    IR1       8          13
    IR2      16          16
    IHORIZ    0           0
    AJN       1.8581      0.2919
    Z1JN      0.0         0.0
    Z2JN      0.0         1.2192
    CJN       1.E-5       2.8
    KFILTER   0.0         0.0
    FGAS1JN   1.0         1.0
    XLJN      0.001       3.048
    XWJN      1.2192      0.6096
    XHJN      1.5240      0.8621
  END PATHS
*
* Fan from exhaust duct to ambient
*
* fan flow rate= 17500 cfm = 8.2591 m^3/s
* fan flow rate= 0 m^3/s
*
* Path 26: Exhaust duct to ambient
* CJN not used, constant volumetric flow rate
* Set AJN to an arbitrary positive value
*  so code does not bypass the junction
* IR1 = 16 = Exhaust duct
* Z1JN = 0 m
* IR2 = 15 = Ambient (atmosphere)
* Z2JN = 15 m (est.; stack height = 200'?)
*
  PATHS      26
    LABEL    FAN
    IJTYP     1
    ICCJN     1
    IR1      16
    IR2      15
    IHORIZ    0
    AJN       0.0
    Z1JN      0.0
    Z2JN     15.0
    CJN       1.0
!    KFILTER  0.0
!    FGAS1JN  1.0
!    IFAN     1
!    WVFAN    8.2591
  END PATHS
*
* Cell 2L and canyon to ambient
*
* Path 28: Ambient to Canyon
* Leakage modeled using KFILTER
* 17500 cfm (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_10 +  ZTOP_10 / 2 - ELEVATION_15
*      = 7.5438 m + 14.9352 m / 2 - 7.5438 m
*      = 7.4676 m
* IR2 = 10 = Canyon
* Z2JN = ZTOP_10 / 2
*      = 7.4676 m
*
* Path 29: Ambient to Cell 2L
* Leakage modeled using KFILTER
* 17500 cmf (82.6 m^3/s) at 0.15 in w.g. (35.9 Pa)
* Assume equal split between canyon leakage and
* access tunnel leakage.
```

```
* Hence, KFILTER= 35.9 / (82.6/2) = 0.870
* IR1 = 15 = Ambient (atmosphere)
* Z1JN = ELEVATION_12 + ZTOP_12 / 2 - ELEVATION_15
*      = -1.8542 m + 7.5692 m / 2 - 7.5438 m
*      = -5.6134 m
* IR2 = 12 = Cell 2L
* Z2JN = ZTOP_12 / 2
*      = 7.5692 m / 2
*      = 3.7846 m
*
  PATHS      28         29
    LABEL   AMB-CANYON AMB-C2L
    IJTYP    8          8
    ICCJN    0          0
    IR1      15         15
    IR2      10         12
    IHORIZ   1          1
    AJN      1.0        1.0
    Z1JN     7.4676     -5.6134
    Z2JN     7.4676      3.7846
    CJN      2.8        2.8
    KFILTER  0.870      0.870
    FGAS1JN  1.0        1.0
    XLJN     1.0        1.0
    XWJN     1.0        1.0
    XHJN     1.0        1.0
  END PATHS
*
END JUNCTIONS
```

APPENDIX C: SELECTED FATE™ MODEL IMPROVEMENT MEMOS

This Appendix contains five FAI memoranda describing improved FATE™ computer code models for modeling sludge behavior during transportation and storage.

Sections C.1 through C.3 describe the theoretical basis for global natural circulation between standard cells and the canyon in T Plant, implementation and testing of the model for FATE Quality Assurance, and an example application demonstrating that the circulation flow predicted by FATE is in agreement with a simple hand calculation. The important conclusion of these memos is that such global circulation will exist, which is beneficial in achieving low hydrogen concentrations in a cell.

Sections C.4 and C.5 describe the theoretical basis for natural convection heat transfer around the bottom head of an STSC, and implementation and testing of the model in FATE for FATE Quality Assurance. The important conclusion is that the holes in the STSC skirt are sufficient to credit this heat removal process, which is beneficial for thermal stability of sludge.

Note that the individual memoranda are copied here verbatim, so that figure, table, equation, and section numbers are given as in the original work, as are references.

C.1 Buoyancy-Driven Flows in T Plant When the Ventilation System is Not Operating

DATE: March 1, 2010

TO: Michael E. Johnson
James P. Sloughter
Bob Apthorpe
Sung Jin Lee
Marty Plys

FROM: Michael Epstein Vice President, Consulting Services

SUBJECT: **Buoyancy-Driven Flows in T Plant When the Ventilation System is Not Operating**

INTRODUCTION

Previous analyses of sludge storage at T Plant have conservatively assumed stagnant cell conditions (no T Plant ventilation) allowing only exchange flow between the cell of interest and the canyon via gaps in cover blocks. The general condition under which global natural circulation within T Plant can enhance the ventilation rate within a process cell, relative to the local countercurrent flow ventilation rate presently used in the FATE T Plant calculations, is examined analytically. The results clearly show that global natural circulation is the dominant mode of process cell ventilation and that significant ventilation enhancement will likely be predicted once global circulation is incorporated into the FATE code.

A global T Plant stack effect is possible, but at the present time its potential magnitude is unknown, so that this work considers zero stack effect, which is conservative. Also, this work pertains to all the standard cells from sections 3 through 20 which are connected via a common manifold, the main ventilation duct. The other cells which are connected by an external clay pipe do not participate in this global natural circulation process, but may in principle create a similar flow pattern between themselves and the canyon.

CONDITION FOR COUNTERCURRENT COVER BLOCK FLOW

Consider the process cell at T Plant illustrated in Fig. 1 whose air density ρ is lower than that of neighbor cells and lower than the canyon air density ρ_{cn} due to heat, steam and hydrogen generation within the cell. Even if the T Plant vent fan system is not operating, a global natural convection pattern is established between the high-density-atmosphere cells (cold cells) that do not contain process material and the low-density-atmosphere cells that contain process material and generate heat (hot cells) or generate both heat and gas (process cell). Because of the global circulation pattern air is supplied to the process cell in Fig. 1 from the ventilation duct at a volumetric flow rate Q_u. The flow between the process cell and the canyon through the gaps in the cover blocks could be one way flow from cell to canyon. Alternatively, if the imposed global flow Q_u is sufficiently weak, a countercurrent exchange flow between the cell and the canyon is established within the cover blocks passages. The countercurrent flow case is shown in Fig. 1, where Q_{BF} is the buoyant down flow due to the density difference $\rho_{cn} - \rho$.

The flow through the gaps in the cover blocks is laminar and the pressure drop ΔP_f over the vertical extent H of the blocks due to gas flow friction is well represented by the product of a known constant K ("filter constant") and the volumetric flow rate Q:

$$\Delta P_f = KQ \tag{1}$$

where K is in units Pa s m^{-3} and is based on the total gap flow area. If P_1 is the pressure in the cell just below the cover blocks and P_{cn} is the pressure in the canyon just above the cover blocks (see Fig. 1), the momentum equation for the upward flow through the cover blocks is

$$P_1 - P_{cn} = \frac{K}{f} Q + \rho g H \tag{2}$$

where f is the fraction of the cover block flow area through which the upward flow from cell to canyon is transmitted. The momentum equation for the downward buoyant flow is

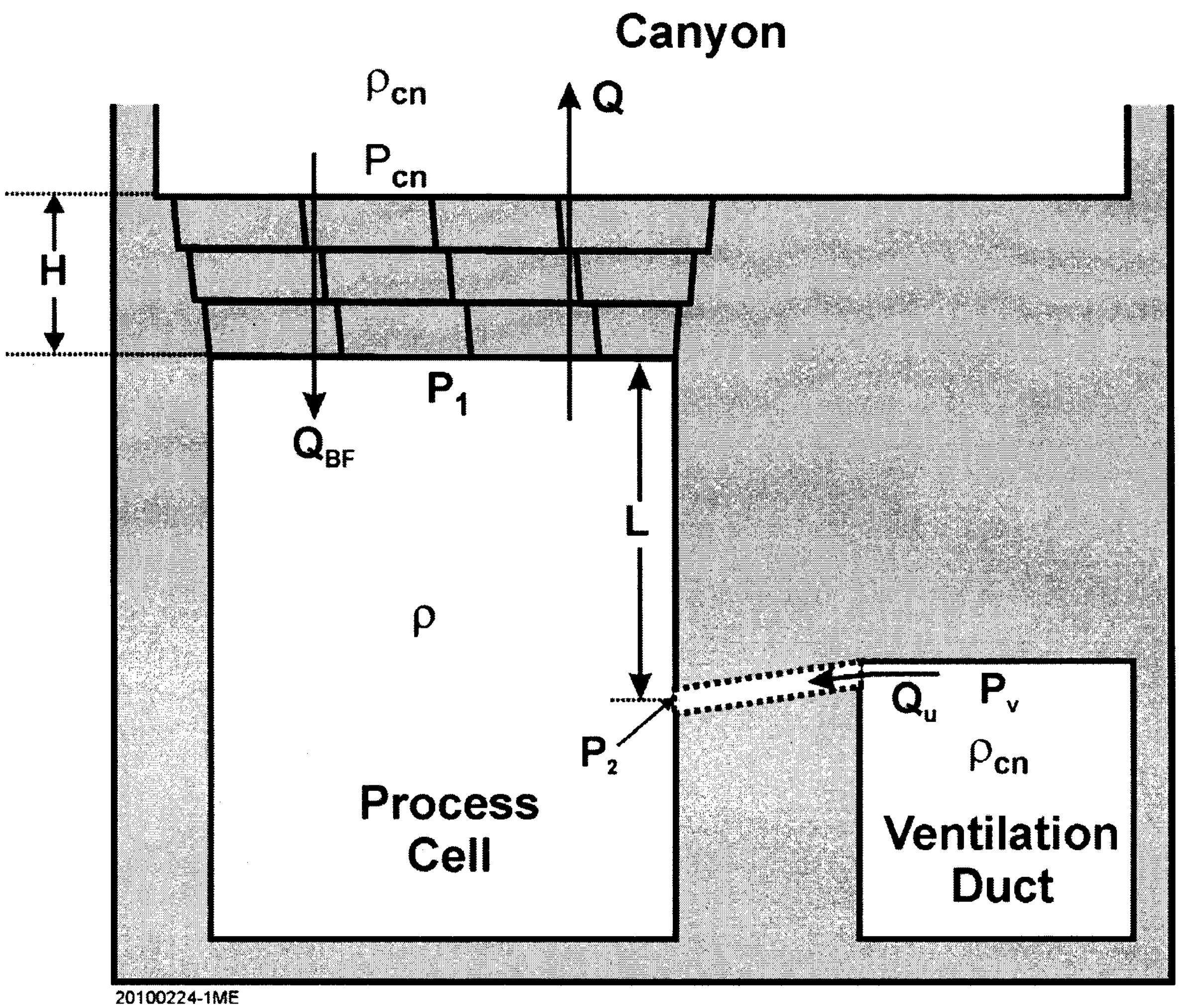


Figure 1 Countercurrent flow in cover blocks above process cell. Both heat and gas are generated in the process cell. In the case of unidirectional flow in cover blocks; $Q_{BF} = 0$, $Q = Q_u$.

$$P_{cn} - P_1 = \frac{K}{1-f} Q_{BF} - \rho_{cn} gH \tag{3}$$

Adding Eqs. (2) and (3):

$$\frac{K}{f} Q + \frac{K}{1-f} Q_{BF} = (\rho_{cn} - \rho)\, gH \tag{4}$$

A volumetric flow balance on the cell requires that

$$Q = Q_u + Q_{BF} \tag{5}$$

Replacing Q in Eq. (4) with Eq. (5) gives

$$\frac{K}{f}(Q_u + Q_{BF}) + \frac{K}{1-f} Q_{BF} = (\rho_{cn} - \rho)\, gH \tag{6}$$

Suppose the global flow imposed on the cell vanishes ($Q_u = 0$) and the flow through the cover blocks is purely countercurrent (cc) buoyant flow $Q_{BF} = Q_{cc}$. It is reasonable to assume that under purely buoyant flow conditions the upward and downward flows each occupy half of the available gap flow areas so that $f = ½$. From Eq. (6) the purely buoyant countercurrent volumetric flow rate is then

$$Q_{cc} = \frac{(\rho_{cn} - \rho)\, gH}{4K} \tag{7}$$

Equation (6) may be rewritten as

$$\frac{Q_u + Q_{BF}}{f} + \frac{Q_{BF}}{1-f} = 4Q_{cc} \tag{8}$$

The purging (or "flooding") flow rate $Q_u = q$ necessary to reduce Q_{BF} to zero is achieved when all the flow through the cover blocks is upward. Thus in Eq. (8), setting $Q_{BF} = 0$ and then setting $f = 1.0$ (see Eq. 7):

$$q = 4.0\, Q_{cc} = \frac{(\rho_{cn} - \rho)\, gH}{K} \tag{9}$$

Dividing Eq. (8) by q and using Eq. (9) where q divides Q_{BF} results in

$$\frac{1}{f}\left(\frac{Q_u}{q}+\frac{Q_{BF}}{4.0\,Q_{cc}}\right)+\frac{1}{1-f}\,\frac{Q_{BF}}{4.0\,Q_{cc}}=1.0 \tag{10}$$

Solving for Q_{BF}/Q_{cc} yields

$$\frac{Q_{BF}}{Q_{cc}}=4.0\,f\,(1-f)\left(1.0-\frac{Q_u}{qf}\right) \tag{11}$$

We now desire to develop and interpolation formula for estimating the values of Q_{BF} and f between the limits of purely buoyant (countercurrent) flow through the cover blocks and one way flooding flow due to natural-convection-driven circulation within T Plant. In order to accomplish this another constraint must be imposed on the cover block flow. A physically meaningful constraint is to seek the value of the flow area fraction f that maximizes Q_{BF} in Eq. (11) for a fixed value of Q_u. Differentiating Eq. (11) with respect to f and using the condition $dQ_{BF}/dx = 0$ yields

$$f=\frac{1}{2}+\frac{Q_u}{2q} \tag{12}$$

Substituting this result into Eq. (11):

$$\frac{Q_{BF}}{Q_{cc}}=\left(1-\frac{Q_u}{q}\right)^2 \tag{13}$$

Interestingly enough, the functional form of Eq. (13) is identical to available expressions for the actual combined free and forced convection through an opening in a wall or ceiling (Epstein and Kenton, 1989). In view of this finding the procedure recommended by Epstein and Kenton for dealing with exchange flow in a multicompartment system would appear valid for application to T Plant. The global circulation flow is calculated by first assuming one-way flow throughout the plant, including the process cell of interest. In this manner a Q_u is calculated for the subject process cell. Then the cover block flow is checked for countercurrent natural convection flow by calculating q (Eq. 9) and comparing it with Q_u. If the cover block flow above the process cell is such that $Q_u < q$ then the exchange flow rate through the cover block is recomputed using Eq. (13). The Q_u to be input in Eq. (13) is that already obtained from the one-way global circulation analysis of T Plant. If $Q_u > q$ then one-way upward flow Q_u through the cover blocks prevails ($Q_{BF} = 0$). The equation for Q_u is derived in the next section.

GLOBAL CIRCULATION CURRENT IN T PLANT

As already indicated there are three types of cells. There is one process cell within which heat and gas is generated; it is illustrated in Fig. 1. For the purpose of estimating Q_u, $Q_{BF} = 0$ and $Q = Q_u$. Figure 2 shows a "hot cell" within which only heat is generated. The density of the air in a hot cell is denoted by the symbol ρ_h. There are about 4 or 5 hot cells. As part of the global circulation pattern and much like the process cell, the hot cells draw in air from the ventilation duct and supply air to the canyon, but at a different volumetric rate denoted by Q_h. The remaining cells of which there are many are called "cold cells". The temperature and density of a cold cell atmosphere is the same as those of the canyon atmosphere. The global circulation drives air into a cold cell from the canyon and out of the cold cell into the ventilation duct (see Fig. 3). Accordingly, the density of the air in the ventilation duct is taken to be the same as the density of the canyon atmosphere, namely ρ_{cn}.

The following hydrostatic relations may be written for the cell atmosphere pressures shown in Figs. 1 to 3

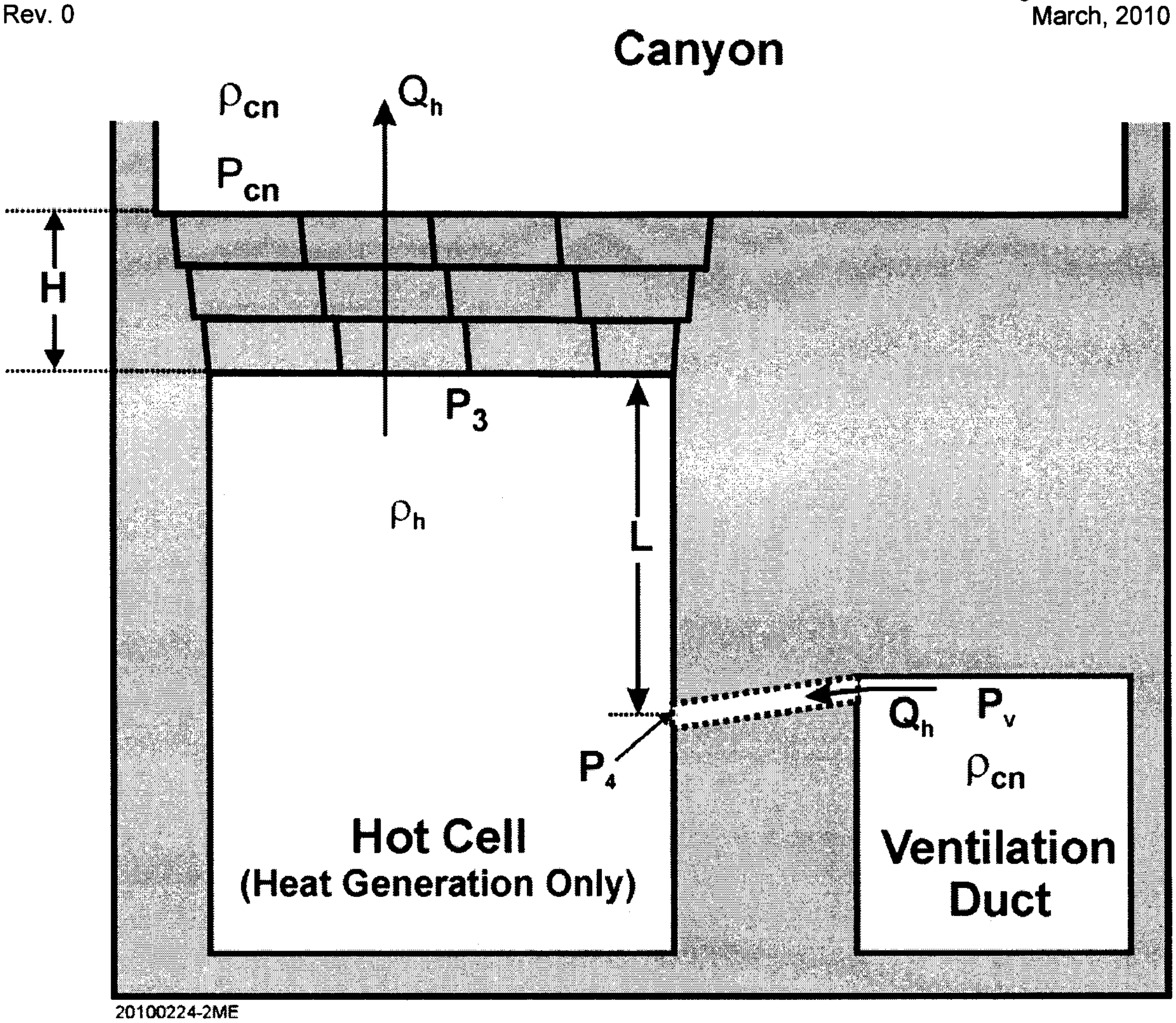


Figure 2 One-way buoyancy-driven flow through cell with heat generation.

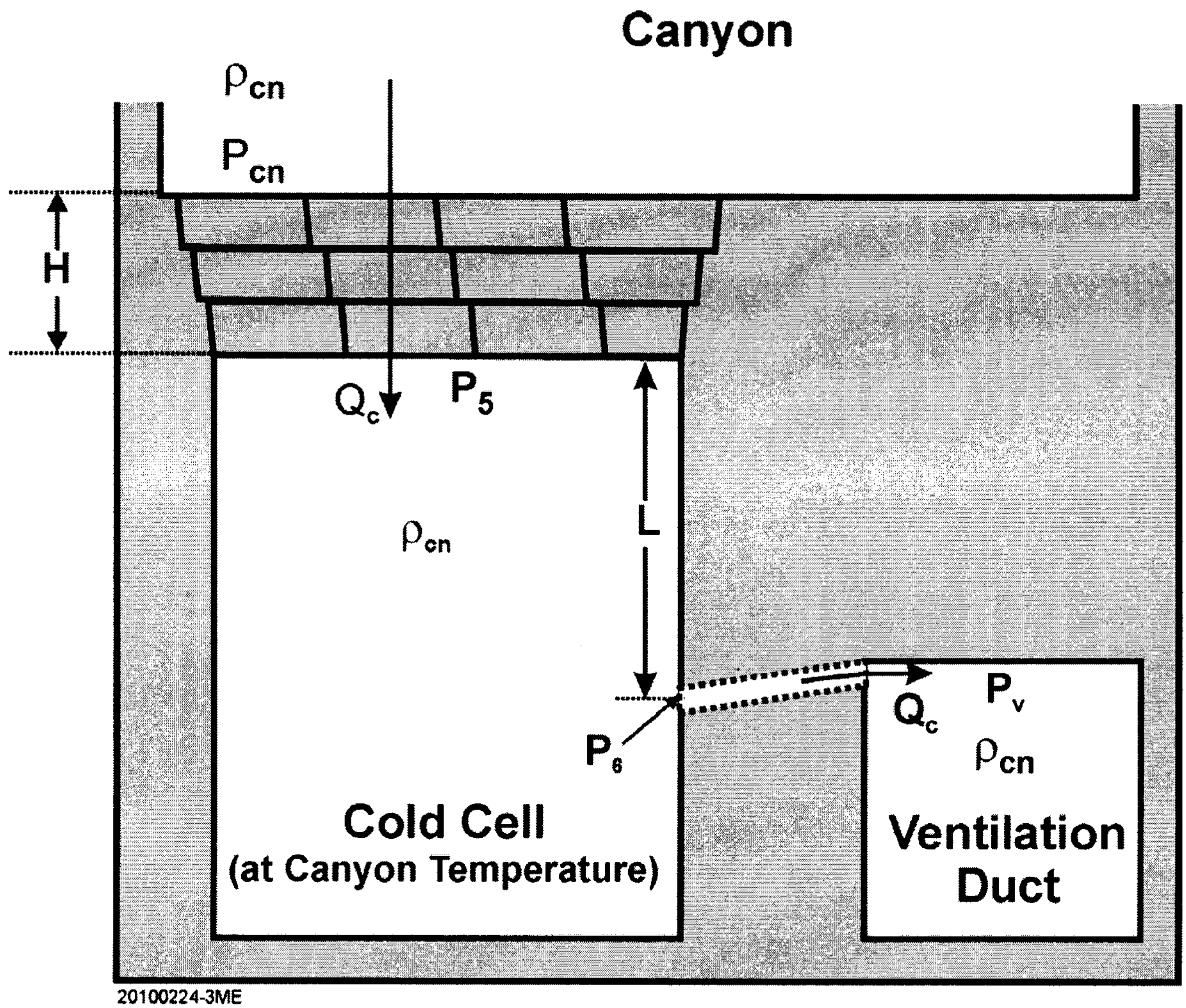


Figure 3 One-way buoyancy-driven flow through cold cell. The temperature and density of the cold cell atmosphere is the same as those of the canyon atmosphere.

$$P_2 = P_1 + \rho g L \tag{14}$$

$$P_2 = P_v + \rho_{cn} g \delta \tag{15}$$

$$P_4 = P_3 + \rho_h g L \tag{16}$$

$$P_4 = P_v + \rho_{cn} g \delta \tag{17}$$

$$P_6 = P_5 + \rho_{cn} g L \tag{18}$$

$$P_6 = P_v + \rho_{cn} g \delta \tag{19}$$

where L is the distance between the bottom of the cover blocks and the center of the ventilation pipe which connects the cell to the ventilation duct (see Figs. 1 to 3), P_v is the pressure at the top of the ventilation duct, and δ is the vertical rise distance (not shown in the figures) of the ventilation pipe from the cell to the ventilation duct. In writing Eqs. (15), (17) and (19), flow frictional resistance in the ventilation pipe was ignored since it can be shown to be negligible compared with flow frictional resistance in the cover block gaps.

The momentum equations for the one-way flows through the blocks that cover the process cell, a hot cell and a cold cell are, respectively,

$$P_1 - P_{cn} = KQ_u + \rho g H \tag{20}$$

$$P_3 - P_{cn} = KQ_h + \rho_h g H \tag{21}$$

$$P_{cn} - P_5 + \rho_{cn} g H = KQ_c \tag{22}$$

Eliminating P_2 between Eqs. (14) and (15), P_4 between Eqs. (16) and (17) and P_6 between Eqs. (18) and (19):

$$P_1 + \rho g L = P_v + \rho_{cn} g \delta \tag{23}$$

$$P_3 + \rho_h g L = P_v + \rho_{cn} g \delta \tag{24}$$

$$P_5 + \rho_{cn} g L = P_v + \rho_{cn} g \delta \tag{25}$$

Adding Eqs. (20) and (22) and adding Eqs. (21) and (22):

$$P_1 - P_5 + (\rho_{cn} - \rho) g H = K (Q_u + Q_c) \tag{26}$$

$$P_3 - P_5 + (\rho_{cn} - \rho_h)\, gH = K\,(Q_h + Q_c) \tag{27}$$

Eliminating P_1, P_3, and P_5 between Eqs. (23) to (25) and Eqs. (26) and (27) gives

$$(\rho_{cn} - \rho)\, g\,(L + H) = K\,(Q_u + Q_c) \tag{28}$$

$$(\rho_{cn} - \rho_h)\, g\,(L + H) = K\,(Q_h + Q_c) \tag{29}$$

The overall T Plant volumetric flow balance that includes the total number of cold and hot cells, denoted respectively by N_c and N_h, is

$$N_c Q_c = N_h Q_h + Q_u \tag{30}$$

Equations (28) to (30) comprise a linear algebraic system for the volumetric flows Q_c, Q_h and Q_u. The solutions of this system are

$$Q_c = \frac{g(L+H)}{KN_{tot}}\left[N_h\left(\rho_{cn} - \rho_h\right) + \left(\rho_{cn} - \rho\right)\right] \tag{31}$$

$$Q_h = \frac{g(L+H)}{KN_{tot}}\left[N_c\left(\rho_{cn} - \rho_h\right) - \left(\rho_h - \rho\right)\right] \tag{32}$$

$$Q_u = \frac{g(L+H)}{KN_{tot}}\left[N_c\left(\rho_{cn} - \rho\right) + N_h\left(\rho_h - \rho\right)\right] \tag{33}$$

where N_{tot} is the total number of cells (cold + hot + process):

$$N_{tot} = N_c + N_h + 1 \tag{34}$$

COUNTERCURRENT VERSUS UNIDIRECTIONAL FLOW IN THE COVER BLOCKS ABOVE THE PROCESS CELL

Recall that the condition for unidirectional flow through the blocks that cover the process cell is

$$\frac{Q_u}{q} > 1.0 \tag{35}$$

Using Eqs. (9) and (33) to evaluate the left-hand side of Eq. (35), the condition for unidirectional flow becomes

$$\frac{N_c}{N_{tot}}\left(\frac{L}{H}+1\right)\left[1.0+\frac{N_h\left(\rho_h-\rho\right)}{N_c\left(\rho_{cn}-\rho\right)}\right] > 1.0 \tag{36}$$

Since the process cell atmosphere is always less dense than the hot cell and canyon atmospheres the term in brackets on the left-hand side of the above inequality is always greater than unity. The total number of cells is N_{tot} = 36 and the number of cold cells is N_c = 31. The vertical extent of the cover blocks is H = 1.83 m and the vent pipe is located a vertical distance L = 3.96 m below the cover blocks. Therefore

$$\frac{N_c}{N_{tot}}\left(\frac{L}{H}+1\right) = 2.72 \tag{37}$$

and Eq. (36) is always satisfied. This means that the countercurrent flow pattern through the cover blocks shown in Fig. 1 does not occur. Instead $Q_{BF} = 0$ and $Q = Q_u$ where Q_u is given by Eq. (33). In other words the global natural circulation in T Plant is always strong enough to prevent downward buoyant flow in the cover blocks above the process cell.

It is also instructive to evaluate the ratio of the unidirectional flow to the countercurrent flow (see Eqs. 7 and 33)

$$\frac{Q_u}{Q_{cc}} = \frac{4.0\,N_c}{N_{tot}}\left(\frac{L}{H}+1\right) \cong 10.9 \tag{38}$$

where the small term $N_h\,(\rho_h - \rho)$ in Eq. (33) was ignored. It follows from Eq. (38) that large enhancements in the process cell ventilation rate can be expected (although not as large as indicated by Eq. 38) by replacing the countercurrent flow model with the more realistic global circulation driven unidirectional flow model (Eq. 33).

REFERENCE

Epstein, M. and Kenton, M. A., 1989, "Combined Natural Convection and Forced Flow Through Small Openings in a Horizontal Partition, With Special Reference to Flows in Multicompartment Enclosures," J. Heat Transfer 111, pp. 980-987.

ME:lak

C.2 FATE Ceiling Crack Flow Model and Testing

DATE: March 4, 2010

TO: Bob Apthorpe, Sung Jin Lee, and Michael Epstein

FROM: Marty Plys; Desk 1-630-887-5207, Cell 1-312-953-7299, plys@fauske.com

SUBJECT: **FATE Ceiling Crack Flow Model and Testing**

The attached pages contain a section for FAI/10-93, the new FATE 2.061 Software Change Specification (SCS). The equation numbers will need to be revised to follow numbering in the SCS. The equations have been taken from "Buoyancy-Driven Flows in T Plant when the Ventilation System is Not Operating," FAI memorandum by M. Epstein to M.E. Johnson et al, March 1, 2010.

6.7 Ceiling Gap Flow Model

Similar to the door gap configuration discussed above, a ceiling gap flow model has been added to consider the case where two regions can exchange flow via narrow gaps in a partition that forms the ceiling of the underlying region and the floor of the overlying region. This is a typical "cover block" configuration in which one or more cover blocks are used to close a hatch between two floor levels, or to cover a process cell. The key feature of this junction model is that the narrow gaps lead to laminar flow, so that the flow rate and pressure drop are linearly proportional. In FATE, this kind of flow characteristic is treated by using the filter resistance KFILTER, and setting a small value for the loss coefficient (which multiplies the square of the velocity). However, unlike a filter flow path, counter-current flow can occur through the gaps, in which some gaps carry flow upward and some carry flow downward. Therefore, a special junction type is required to account for the possibility of unidirectional and countercurrent flow.

A pressure difference will cause unidirectional flow through ceiling gaps in a manner identical to the flow through door gaps. The value of the filter resistance KFILTER, denoted by the symbol K, is derived as shown in the discussion of the door gap model. The counter-current flow for ceiling gaps is derived next.

6.7.1 Counter-Current Ceiling Gap Flow

Consider the geometry shown in Figure 6-16 in which a region of relatively lower gas density ρ is at lower elevation than another region of relatively higher gas density ρ_2. These regions communicate via gaps in the structure that forms the ceiling of the lower elevation region and the floor of the higher elevation region. In the absence of a ventilation flow, this is an unstable configuration, and high density air from the higher elevation region will circulate downward at a rate Q (m^3/s), and low density air from the lower elevation will circulate upward at a rate Q_{BF}, and these two rates will be equal, $Q = Q_{BF}$. This circulation pattern is called countercurrent flow. When the ventilation flow out from the lower elevation region Q_v is sufficiently weak, countercurrent flow can still occur, but there must also be a net flow of equal magnitude into the lower region from the higher region. The analysis that follows will quantify the magnitude of the flow rates and identify the condition at which the countercurrent flow is prevented by a sufficiently high value of the ventilation flow.

<u>Momentum Balance</u>

The flow through the gaps is laminar and the pressure drop ΔP_f over the vertical extent H of the gaps due to gas flow friction is well represented by the product of a known constant K ("filter constant") and the volumetric flow rate Q:

$$\Delta P_f = \frac{12\mu L}{\delta^3 p} Q = K\,Q \qquad (1)$$

where K is in units Pa s m^{-3}, μ is the gas viscosity, L represents the length along the flow path through the gap which is approximately the same as H, δ is the width of the gap, and p is the perimeter of the gap (so the gap cross-sectional area is the product δ x p). If P_1 is the pressure in the lower region just below the gaps and P_2 is the pressure in the upper region just above the gaps, the momentum equation for the downward flow through the gaps is

$$P_2 - P_1 = \frac{K}{f} Q - \rho_2 g H \tag{2}$$

where f is the fraction of the gap flow area through which the downward flow is transmitted. The momentum equation for the upward buoyant flow is

$$P_1 - P_2 = \frac{K}{1-f} Q_{BF} + \rho g H \tag{3}$$

Adding the two momentum equations,

$$\frac{K}{f} Q + \frac{K}{1-f} Q_{BF} = (\rho_2 - \rho) g H \tag{4}$$

A volumetric flow balance on the lower region requires that

$$Q = Q_v + Q_{BF} \tag{5}$$

Eliminating Q between these equations

$$\frac{K}{f}(Q_v + Q_{BF}) + \frac{K}{1-f} Q_{BF} = (\rho_2 - \rho) g H \tag{6}$$

Pure Countercurrent Flow Rate

Suppose the ventilation flow vanishes ($Q_v = 0$) and the flow through the gaps is purely countercurrent (cc) buoyant flow $Q_{BF} = Q_{cc}$. It is reasonable to assume that under purely buoyant flow conditions the upward and downward flows each occupy half of the available gap flow areas so that f = ½. From the preceding equation the purely buoyant countercurrent volumetric flow rate is then

$$Q_{cc} = \frac{(\rho_2 - \rho) g H}{4K} \tag{7}$$

Purge Flow Rate

Next we seek the value of the vent flow that will cause the countercurrent flow to vanish, known as the purge flow. Combining the preceding two equations,

$$\frac{Q_v + Q_{BF}}{f} + \frac{Q_{BF}}{1-f} = 4Q_{cc} \tag{8}$$

The purging (or "flooding") flow rate Q_u = q necessary to reduce Q_{BF} to zero is achieved when all the flow through the gaps is downward. Thus in the preceding equation setting Q_{BF} = 0 and then setting f = 1.0 yields

$$q = 4.0\,Q_{cc} = \frac{(\rho_2 - \rho)\,gH}{K} \tag{9}$$

Combined Countercurrent and Unidirectional Flow

We now desire to develop an interpolation formula for estimating the values of Q_{BF} and f between the limits of purely buoyant (countercurrent) flow and the unidirectional purge flow due to ventilation. We expect Q_{BF} to vary in the range $0 \le Q_{BF} \le Q_{cc}$ as the ventilation flow varies over the range $q \ge Q_v \ge 0$. In order to accomplish this, another constraint must be imposed on the cover block flow. A physically meaningful constraint is to seek the value of the flow area fraction f that maximizes Q_{BF} for a fixed value of Q_v. Combining the preceding two equations to obtain the ratio Q_{BF}/Q_{cc} results in

$$\frac{1}{f}\left(\frac{Q_v}{q} + \frac{Q_{BF}}{4.0\,Q_{cc}}\right) + \frac{1}{1-f}\,\frac{Q_{BF}}{4.0\,Q_{cc}} = 1.0 \tag{10}$$

Solving for Q_{BF}/Q_{cc} yields

$$\frac{Q_{BF}}{Q_{cc}} = 4.0\,f\,(1-f)\left(1.0 - \frac{Q_v}{qf}\right) \tag{11}$$

Differentiating this equation with respect to f and using the condition $dQ_{BF}/df = 0$ yields

$$f = \frac{1}{2} + \frac{Q_v}{2q} \tag{12}$$

Combining the preceding two equations yields the desired result for how the countercurrent flow rate Q_{BF} is reduced from its maximum value Q_{cc} due to a unidirectional flow Q_v:

$$\frac{Q_{BF}}{Q_{cc}} = \left(1 - \frac{Q_v}{q}\right)^2 \tag{13}$$

6.7.2 Model Implementation

Interestingly enough, the functional form of this relationship is identical to available expressions for the actual combined free and forced convection through an opening in a wall or ceiling (Epstein and Kenton, 1989), and already implemented in FATE. First, the pressure-driven unidirectional flow through a flow path is calculated; this is the same as the parameter Q_v used above. The purge flow q is then calculated based upon geometry and current densities. If the unidirectional is less than the purge flow, $Q_v < q$ then the pure countercurrent exchange flow rate Q_{cc} is calculated and the final relationship is used for the actual countercurrent flow in the presence of the unidirectional flow. Otherwise if $Q_v > q$ then there is no countercurrent flow, only a unidirectional flow.

The model is implemented in FATE by creating a new subroutine WJEXCHC which is similar to the existing routine WJEXCH for countercurrent flow, and simply implements the equations for Q_{cc}, q, and Q_{BF} given above. The model is employed for a new junction type, IJTYP = 8, which has a filter resistance characteristic.

6.7.3 New Inputs

The existing parameter IJTYP is now allowed a new value, IJTYP = 8 for a ceiling gap junction. For this junction, the loss coefficient CJN and flow area AJN are not used. The flow resistance is input via KFILTER. The height H used in the preceding equations is derived by FATE from the existing inputs for junction elevation Z1JN and Z2JN.

6.7.4 Test Requirements

The ceiling crack flow model should be tested to demonstrate that it can reproduce the expected pure countercurrent flow rate, the quadratic decrease with increasing unidirectional flow, and zero countercurrent flow for a unidirectional flow exceeding the purge flow.

6.7.5 Test Description

The test geometry consists of a lower region of 10 m^3 volume whose atmosphere consists of oxygen and nitrogen at 25 °C, and an upper region of very large volume whose atmosphere consists of pure argon at 25 °C. The height of the lower region is 10 m, and the bottom elevation of the upper region is 12 m, so that the gap height is H = 2 m. The regions are connected by a junction with IJTYP = 8 with a resistance KFILTER = K = 764.3, which is taken from an application of interest. The entire system is adiabatic.

For the first 100 s, pure countercurrent flow is expected to be observed. Starting at 100 s, an air source is introduced into the lower region. The magnitude of the air source flow rate ramps up linearly from 0 kg/s at 100 s to a value equal to the purge rate at 200 s, and double the purge rate at 300 s. It is expected that a quadratic decrease in the countercurrent flow will be observed as the source is introduced, and that the countercurrent flow rate will go to zero when the purge rate is attained.

The density of 21% oxygen, 79% nitrogen in the lower region is 28.84. The lower region pressure is 10^5 Pa and the density of this gas is ρ = 1.1635 kg/m^3. The pressure of the upper region is 99863 Pa due to static head difference, and the density of argon there is ρ_2 = 1.6115 kg/m^3. From the given flow resistance and gap height, the countercurrent flow rate is Q_{cc} = 2.875e-3 m^3/s, and at the average of the two gas densities the mass flow rate is 4.0e-3 kg/s. The purge rate is q = 0.0115 m^3/s and using the air density the purge mass flow is 0.0134 kg/s. If the pure countercurrent flow prevails for the first 100 s of the test, the argon mole fraction in the lower region will be slightly less than 100 x 2.875e-3/10 = 2.87%; a lesser value will be obtained because some argon is carried out with the countercurrent flow.

6.7.6 Test Results

Test results are shown in Figure 6-17. The unidirectional flow (upper left) increases linearly from zero at 100 s. During the first 100 s, the countercurrent flow rate (upper right) is about 0.004 kg/s as expected (see above). The slight decline in this rate over the 100 s is due to the buildup of argon in the lower region (lower left). The expected argon mole fraction in the lower region of 2.87% is not quite obtained at 100s, because of the back-flow of argon. The countercurrent flow declines quadratically with time after 100 s, and becomes nearly zero somewhat before 200 s. This is because the lower region gas density is not the same as used to calculate the purge flow; the density is higher and hence a lower purge flow is sufficient to stop the countercurrent flow, exactly as observed. At 3.5% argon, the lower region gas density is ρ = 1.1792 kg/m^3, the purge flow is q = 0.0111 m^3/s, and the purge mass flow is 0.0129 kg/s.

In conclusion, the test demonstrates all the behavior expected from the test requirements and test description.

6.7.7 Reference

Epstein, M. and Kenton, M.A., 1989, "Combined Natural Convection and Forced Flow Through Small Openings in a Horizontal Partition, with Special Reference to Flows in Multicompartment Enclosures," J. Heat Transfer 111, pp. 980-987.

Figure 6-16. Flow pattern through ceiling gaps for a cell cover block example.

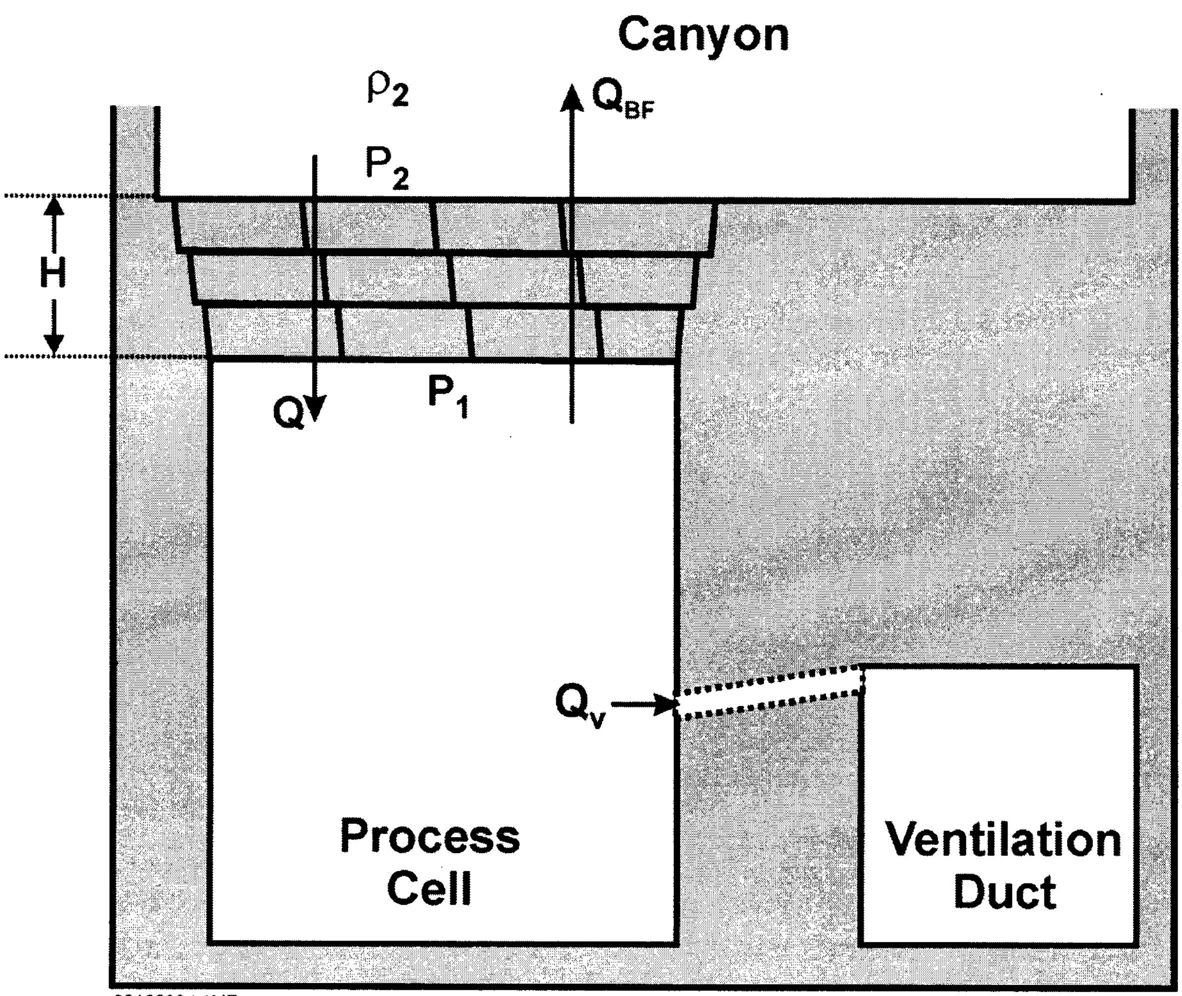
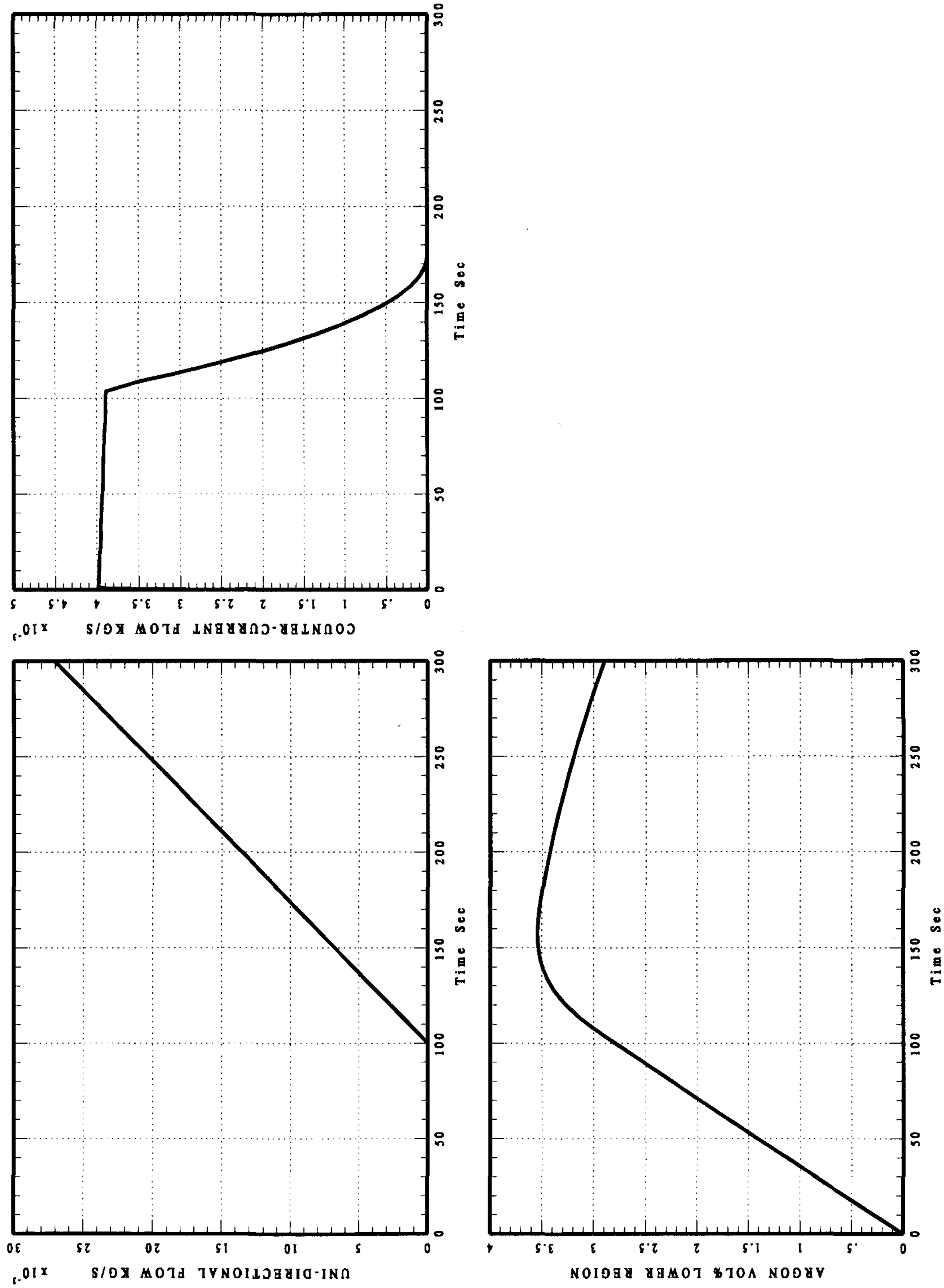


Figure 6-17. Ceiling gap flow test results plots.



C.3 T Plant Circulation Results Quick Look

DATE: March 5, 2010

TO: Jim Sloughter and Mike Johnson, CHPRC K Basins Closure Project

FROM: Marty Plys; Desk 1-630-887-5207, Cell 1-312-953-7299, plys@fauske.com

SUBJECT: **T Plant Circulation Results Quick Look**

In report FAI/10-83 exchange flow between a process cell and the T Plant canyon takes place via counter-current flow through gaps between the cover blocks (Apthorpe et al, 2010). This is the baseline model approach that has been in use since the first sludge analyses in 2002.

A model for buoyancy-driven flow that couples the hot process cell containing the "active" STSC, the remaining cold process cells, and the canyon is presented in a recent memo (Epstein, 2010). The model predicts the following flow rate upward Q (m^3/s) through the hot process cell cover block gaps, which is fed from the ventilation duct and further upstream by downflow from the canyon to cold cells:

$$Q = \frac{g(L+H)}{K}\frac{N_c}{N_{tot}}\left(\rho_{cn} - \rho\right)$$

where g = 9.81 m/s, L = distance between the cell vent centerline and cover blocks, H = thickness of the cover blocks, K = flow resistance of cover block gaps, N_c = number of cold cells, N_{tot} = total number of cells, ρ_{cn} = canyon gas density, and ρ = cell gas density. A priori known values are L + H = 12 ft + 6 ft = 5.488 m, K = 382.15 Pa-s/m^3, g = 9.81 m/s^2, N_c = 35, and N_{tot} = 36.

In the same memorandum, a model for counter-current flow though cover block gaps was presented. This was recently implemented into FATE 2.061 and successfully tested (Plys, 2010).

The revised FATE model was used to re-evaluate the worst case from FAI/10-83, SETTRN, settler sludge in a standard T Plant cell with no fans. In the reference calculation, the peak cell hydrogen concentration was just under 4%, and the countercurrent flow rate through the cover block gaps was about 0.001 kg/s. The re-evaluated case is designated SETTRN2B. In this case, the canyon volume is assigned its proper value (as opposed to an infinite air reservoir), and two new regions are added, one representing 35 cold cells, and one for the ventilation duct that connects all the standard cells. The new FATE ceiling gap flow model was used to represent the junction between the hot cell and the canyon and between the cold cells and the canyon. The hot cell and the cold cells are connected to the ventilation duct by 10" diameter vent pipes. Concrete heat structures are used to represent walls of the cold cells, ventilation duct, and canyon. The building nodalization is illustrated in Figure 1.

The results of the re-evaluated case SETTRN2B are shown in Figures 2 and 3, which are in the same format as the figures of FAI/10-83 except that the upper right plot in Figure 3 contains the unidirectional flow rates through the hot and cold cell cover blocks instead of the countercurrent flow rate through the hot cell cover blocks (which is zero as expected). All the process histories for quantities internal to the STSC remain essentially unchanged from the results in FAI/10-83, except that the peak sludge temperature is slightly lower because the peak cell temperature is slightly lower.

The significant new results are found in Figure 3 on the upper and lower right. In the upper right, the gas flow upward through the hot cell cover blocks has a peak value of about 4.75×10^{-3} kg/s, and a long-term value of about 3.5×10^{-3} kg/s. This peak flow is about 5 times greater than the peak flow for the isolated cell model of FAI/10-83. Note that the cold cell flow rate has diurnal variation about a mean value equal to the hot cell flow rate; this is due to diurnal pressure variation that is imposed on the canyon. This diurnal variation does not have a significant impact on the circulation flow rate through the hot cell. The peak hydrogen concentration in the cell (lower right) is about 1%, or 25% of the LFL which is desirable.

Detailed FATE output for at the end of the calculation provides the gas densities for the canyon ρ_{cn} = 1.130 kg/m^3 and for the hot cell ρ = 1.107 kg/m^3. Inserting these and the other known values into the model equation above yields a predicted flow rate Q = 3.2×10^{-3} m^3/s, and multiplying by the cell density the flow rate is 3.5×10^{-3} kg/s, in very good agreement with the FATE calculation.

In conclusion, the revised FATE code is capable of predicting circulation flows internal to T Plant that are in agreement with a closed form model. The natural circulation flow is much greater than pure countercurrent flow that has been previously modeled. Future work for T Plant will invoke this new FATE model and employ a balance of T Plant input model similar to the draft model used here.

References

Apthorpe, R., S.J. Lee, and M. Plys, 2010, "Thermal and Gas Analyses for a Sludge Transfer and Storage Container (STSC) at T Plant (Draft)," FAI/10-83, Fauske & Associates, LLC, February.

Epstein, M., 2010, "Buoyancy-Driven Flows in T Plant when the Ventilation System is Not Operating," FAI memorandum to M.E. Johnson et al, March 1.

Plys, M.G., 2010, "FATE Ceiling Crack Flow Model and Testing," FAI memorandum to R. Apthorpe, S.J. Lee, and M. Epstein, March 4.

Figure 1: T Plant building model for circulation between the canyon and standard cells. One "hot" process cell contains STSCs. 35 empty "cold" standard process cells are lumped together. The ventilation duct elevation is the same as the cell elevation. Junctions between the cells and canyon are gaps in the cell cover blocks, junctions between the cells and vent duct are 10" diameter. Cells in sections HE, 1, and 2 are not modeled, intrusion via cell 1L is not modeled, and the vent duct exit, filter, and stack are not modeled.

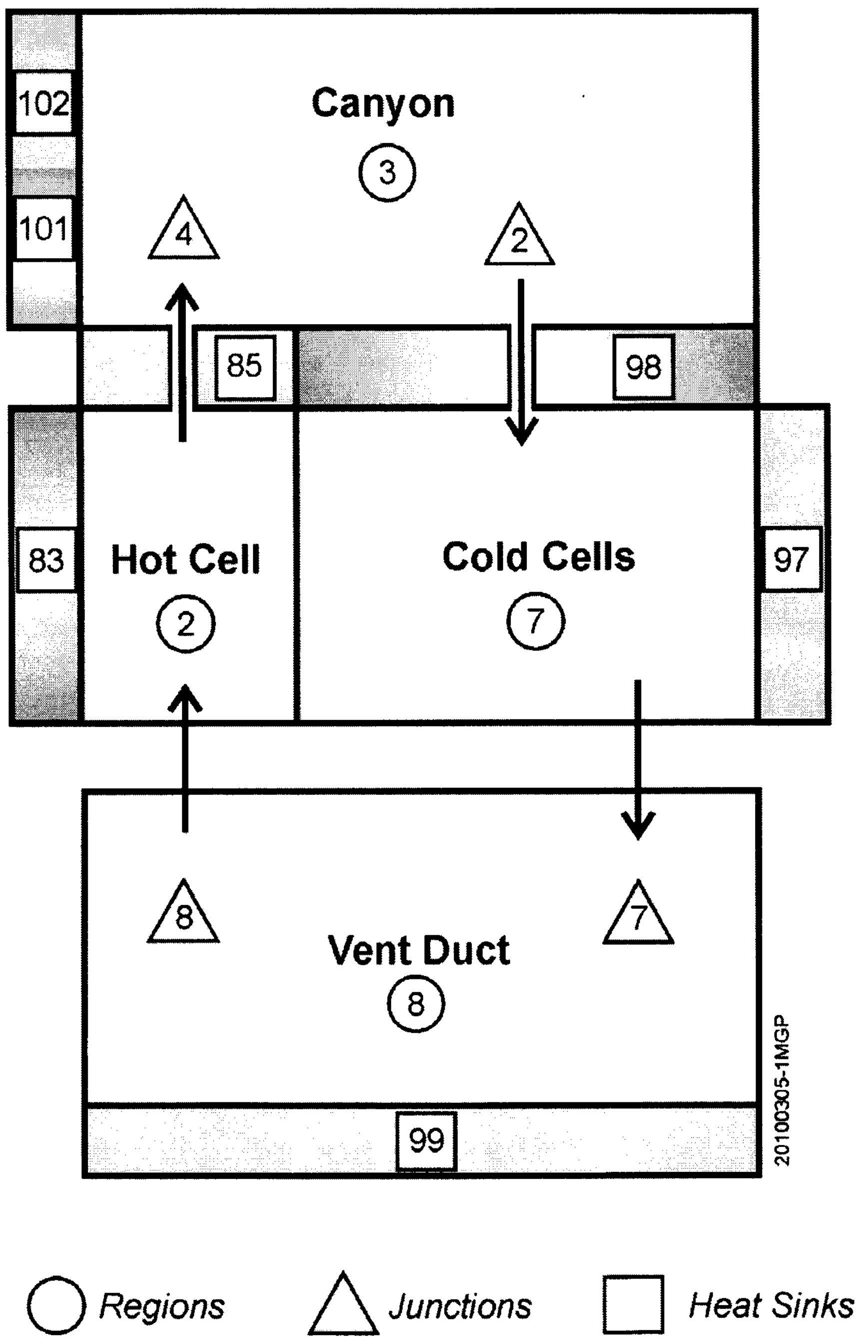


Figure 2: Transient history plots for case SETTRN2B (1 of 2).

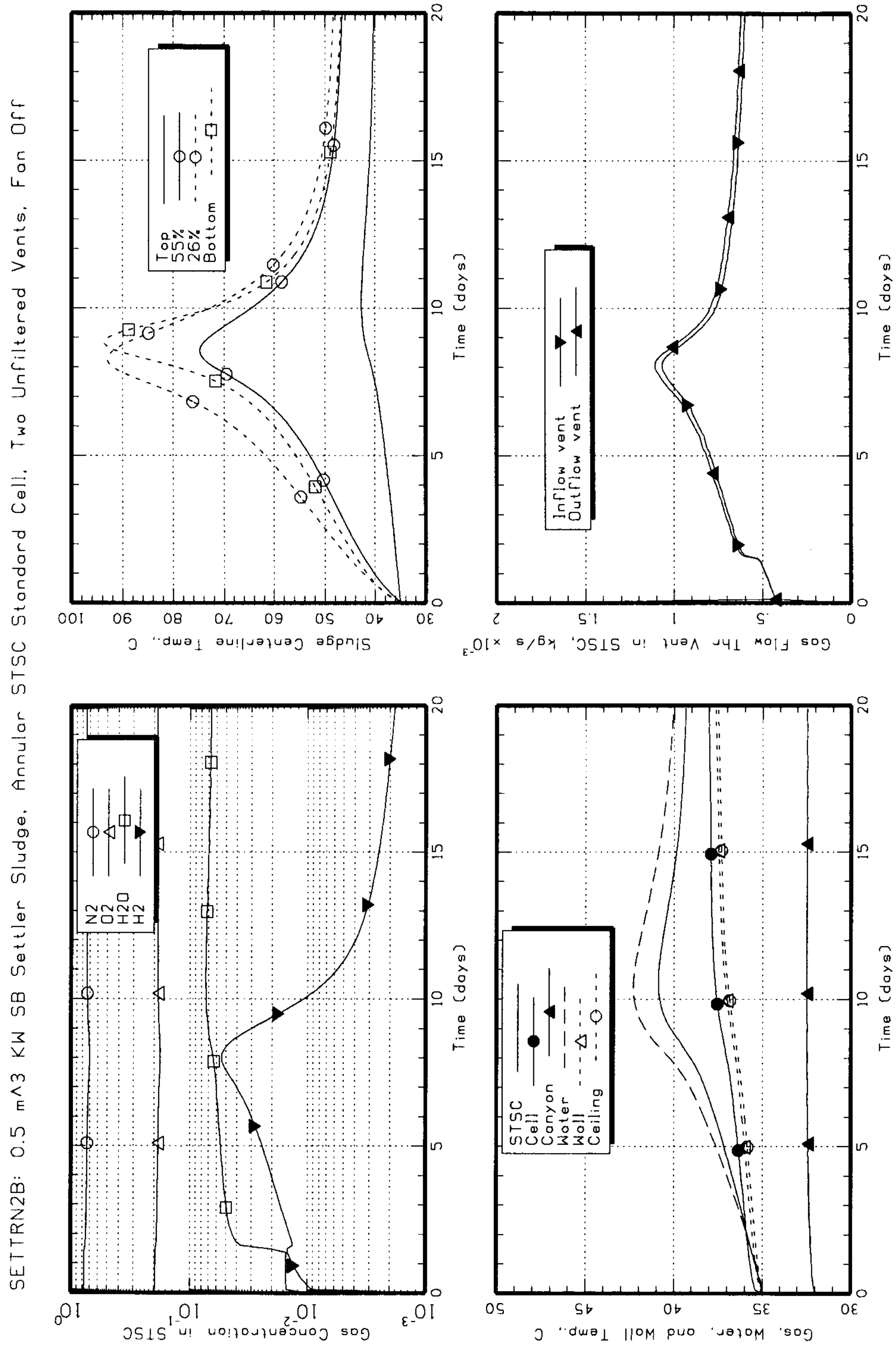
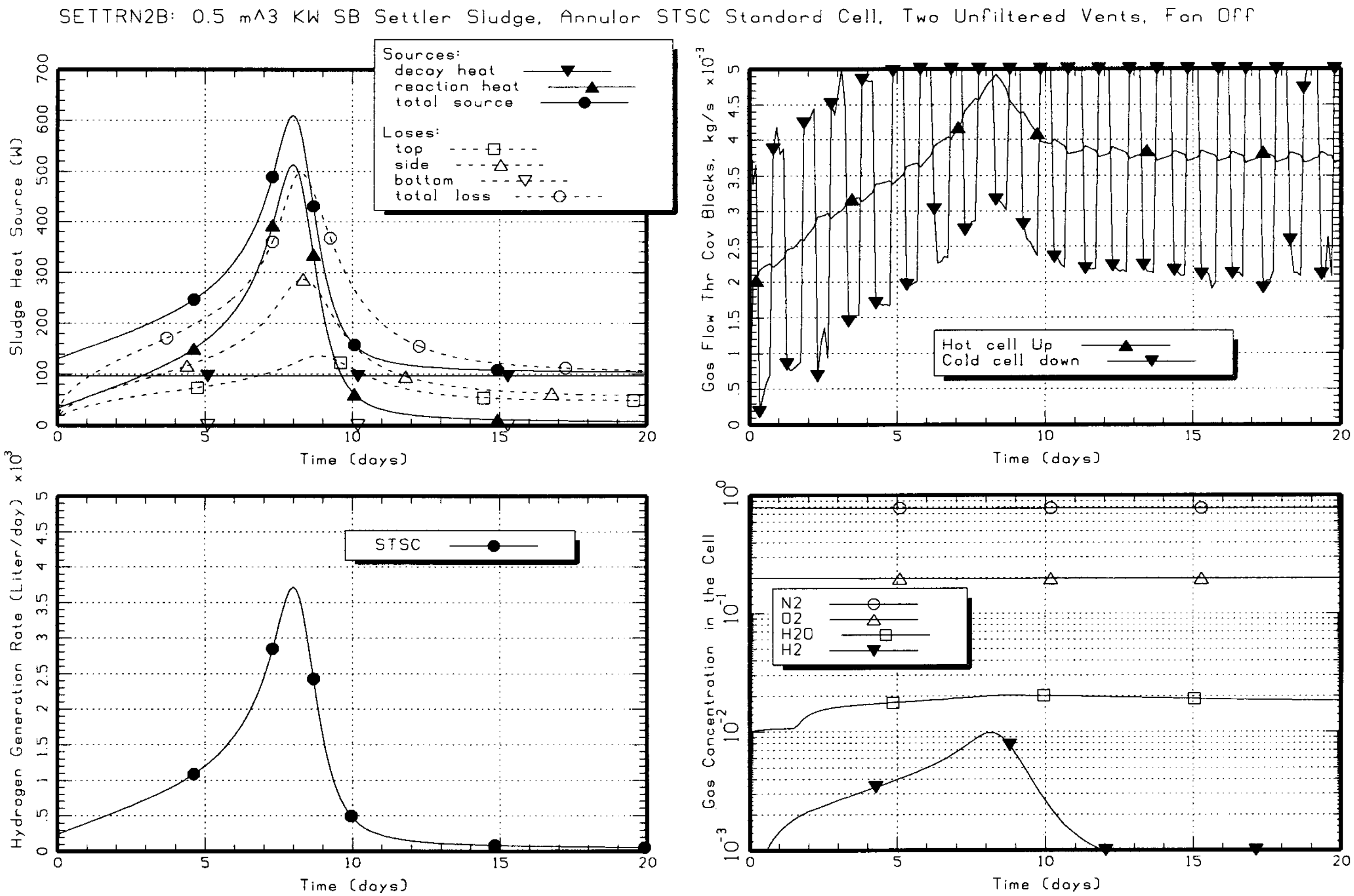


Figure 3: Transient history plots for case SETTRN2B (2 of 2).



C.4 Ventilation Holes in Skirt for STSC Container

DATE: March 4, 2010

TO: Bob Apthorpe
Sung Jin Lee
Marty Plys

FROM: Michael Epstein — Vice President, Consulting Services

SUBJECT: **Ventilation Holes in Skirt for STSC Container**

INTRODUCTION

Natural convection heat transfer off the bottom of the STSC container is likely to be rather weak because the air below the container is trapped in the tight space formed by the drip pan and the vertical, cylindrical skirt (hereafter referred to as the "enclosure"). The heat transfer can be improved if an exchange flow of air between the enclosure and the cell atmosphere is established. Such an exchange flow could be realized by drilling holes circumferentially around the skirt at the bottom and top of the skirt. The relatively cold cell air would then enter the enclosure through the holes at the bottom of the skirt and the hot air that moves radially outward along the bottom of the vessel would leave the enclosure through the holes at the top of the skirt. The two questions addressed in this memo are (i) what is the appropriate coefficient for the vessel wall-to-enclosure air heat transfer rate when the enclosure is ventilated? and (ii) how many holes of a specified size must penetrate the skirt in order to achieve this rate of heat transfer?

HEAT TRANSFER COEFFICIENT

If there were no air flow restrictions between the enclosure and the cell atmosphere, the hot elliptical lower head of the container could be considered to be submerged in an extensive cell air atmosphere. While there are no heat transfer correlations available for predicting rates of heat transfer from a downward facing elliptical surface, heat transfer from an equivalent spherical surface, for which correlations are available, could serve in this regard. However, unless there are many side-by-side holes in the skirt, air flow from the hot boundary layer to the holes in the top of the skirt is obstructed by the solid skirt surfaces between the holes which deflect the flow and force the flow circumferentially to the holes. Therefore, it is felt that selection of a heat transfer coefficient for a sphere in an extensive air atmosphere would result in overestimating the convective heat transfer rate off the lower head.

To err on the conservative side, the elliptical lower head is modeled as a downward facing flat plate. The actual vertical rise of the elliptical surface from its center to its edge is ignored and a smaller hydrostatic head is assumed which is due solely to the fact that the boundary layer is thicker at the center of the flat plate than at the edge. Of course the reduced hydrostatic head tends to decrease the heat transfer rate relative to the heat transfer rate off the actual elliptical surface. On the other hand, the heat transfer correlations that have been reported for downward facing flat surfaces do not include air confinement effects and, therefore, overestimate the heat transfer rate off a partially enclosed surface. It is felt that on balance the downward facing plate approximation is conservative but not overly conservative.

The air flow within the boundary layer on the underside of a hot plate is laminar and the heat transfer coefficient for rectangular or square plates is well represented by the correlation of Aihara et al. (1972):

$$\mathrm{Nu} = 0.5\,\mathrm{Ra}^{1/5} \qquad (1)$$

where Nu and Ra are the Nusselt and Rayleigh numbers based on the half-width R of the plate. Here R is identified with the radius of the waste container's lower head. The heat transfer relation for the square plate is about the same as that for the circular plate (Fujii et al., 1973). The square plate is selected because the structure of the boundary layer beneath the square plate has been investigated more thoroughly than for the circular plate and this boundary layer information is needed to derive an expression for the required number of holes in the skirt.

Had we decided to represent the elliptical lower head by a spherical segment surface (rather than a flat plate) the following correlation by Churchill (1983) would apply:

$$\mathrm{Nu} = 0.382\,\mathrm{Ra}^{1/4} \qquad (2)$$

for air in laminar or turbulent flow. For the Rayleigh numbers of interest ($\mathrm{Ra} \sim 4.0 \times 10^8$) the Nusselt number given by Eq. (2) is about a factor of two higher than that predicted with Eq. (1). Equation (2) may be appropriate if the skirt and drip pan are replaced by a container support structure that does not interfere with the flow of cell air into and out of the enclosure.

Suppose the temperature of the lower head wall is T_w = 50°C and the enclosure air temperature is T_{en} = 35°C. In this temperature range the thermal diffusivity, kinematic viscosity and thermal conductivity of the enclosure air are, respectively, $\nu = 1.82 \times 10^{-5}$ m^2 s^{-1}, $\alpha = 2.60 \times 10^{-5}$ m^2 s^{-1} and $k = 2.81 \times 10^{-2}$ W m^{-1} K^{-1}. The radius of the lower head wall is R = 0.737 m (see Table 1 for a complete list of parameter values). The Rayleigh number in Eq. (1) is then

$$Ra = \frac{g(T_w - T_{en})R^3}{\nu \alpha T_\infty} = 4.10 \times 10^8 \tag{3}$$

and the Nusselt number from Eq. (1) is

$$Nu = 26.4 \tag{4}$$

From the definition of Nu the heat transfer coefficient for natural convection in the enclosure is

$$h = \frac{k\ Nu}{R} = 1.0\ \mathrm{W\ m^{-2}\ K^{-1}} \tag{5}$$

In comparison the effective heat transfer coefficient for the thermal radiation heat loss from the lower head to the ambient at T_∞ = 30°C (with the drip pan acting as a radiation shield) is

$$h_{rad} = \varepsilon\sigma(T_w + T_\infty)(T_w^2 + T_\infty^2) = 2.3\ \mathrm{W\ m^{-2}\ K^{-1}} \tag{6}$$

where the estimated effective emissivity is ε = 0.33 and σ is the Stefan-Boltzmann constant (5.67 x 10^{-8} W m^{-2} K^{-4}). Thus natural convection heat transfer in the enclosure is small but not negligible compared with thermal radiation.

Table 1

Parameter Values

$A_\ell = 2.35\ m^2$	Area of elliptical lower head
$B = 2.611$	Area ratio parameter (see Eq. 18)
$C_D = 0.61$	Discharge coefficient for holes in skirt
$H = 0.3\ m$	Vertical height between upper and lower rows of holes in skirt
$k = 2.81 \times 10^{-2}\ W\ m^{-1}\ K^{-1}$	Thermal conductivity of air
$R = 0.737\ m$	Radius (major semiaxis) of container's elliptical lower head
$T_w = 50°C$	Temperature of elliptical lower head wall (for example problems)
$T_\infty = 30°C$	Temperature of cell atmosphere outside enclosure (for example problems)
$\alpha = 2.60 \times 10^{-5}\ m^2\ s^{-1}$	Thermal diffusivity of air
$\nu = 1.82 \times 10^{-5}\ m^2\ s^{-1}$	Kinematic viscosity of air

REQUIRED NUMBER OF HOLES IN SKIRT

In order to achieve the heat transfer rate given by Eq. (1), the air flow from the cell to the enclosure must be large enough to keep up with the air flow demanded by the thermal boundary layer on the underside of the lower head. The density difference between the cell air and the enclosure air induces a buoyancy driven flow into the enclosure through the lower row of holes of flow area A_h in the skirt and out of the enclosure through the upper row of holes of flow area A_h in the skirt. Denoting by H the vertical distance between the lower and upper rows of holes, it can be readily shown that the volumetric flow of air Q into and out of the enclosure is

$$Q = C_D A_h \left[\frac{(T_{en} - T_\infty) gH}{T_\infty} \right]^{1/2} \tag{7}$$

where T_{en} is the as yet unknown enclosure air temperature, T_∞ is the cell air temperature, g is the gravitational constant and C_D is the discharge coefficient for the holes.

An energy balance written for the enclosure is

$$A_\ell h(T_w - T_{en}) = \rho c_p (T_{en} - T_\infty) Q \tag{8}$$

where A_ℓ is the surface area of the elliptical lower head and c_p and ρ are the specific heat and density of air. Inserting Eq. (1) for h (see also Eqs. 3 and 5) and Eq. (7) for Q into Eq. (8) gives

$$\frac{A_\ell k}{2R} \left(\frac{gR^3}{\nu \alpha T_\infty} \right)^{1/5} (T_w - T_{en})^{6/5} = \rho c_p A_h C_D \left(\frac{gH}{T_\infty} \right)^{1/2} (T_{en} - T_\infty)^{3/2} \tag{9}$$

which is an implicit relation between the enclosure temperature T_{en} and the area A_h of the holes in the upper or lower row of holes that penetrate the skirt.

Now, turning our attention to the boundary layer beneath the elliptical lower head, the experimental and theoretical work of Aihara et al. (1972) and Singh and Birkebak (1969) provided the following equations for the boundary layer thickness δ and the horizontal velocity profile u(y), both evaluated at the edge of the downward facing plate:

$$\delta = \frac{2.0\,R}{Ra^{1/5}} \tag{10}$$

$$u(y) = \frac{27\,U_{max}}{4}\frac{y}{\delta}\left(1-\frac{y}{\delta}\right)^2 \tag{11}$$

where y is the distance coordinate perpendicular to the plate and U_{max} is the maximum fluid velocity within the boundary layer. The expression or U_{max} is

$$U_{max} = \frac{0.8\,\alpha}{R}\,Ra^{2/5} \tag{12}$$

The volumetric flow of air at the edge of the plate Q_p, which equals the volumetric rate at which air is entrained by the boundary layer, is given by the integral

$$Q_p = 2\pi R\int_0^\delta u\,dy = \frac{27\pi}{2}U_{max}R\delta\int_0^1 (1-\xi)\,\xi^2 d\xi = \frac{27\pi}{24}U_{max}R\delta \tag{13}$$

or, from Eqs. (10) and (12),

$$Q_p = 1.8\ \pi\alpha R\ Ra^{1/5} \tag{14}$$

As already mentioned the air flow Q into the enclosure must at least equal the rate Q_p at which the boundary layer entrains air. This condition is represented mathematically as (see Eq. 7)

$$Q_p = 1.8\pi\alpha R\left[\frac{g(T_w - T_{en})R^3}{\nu\alpha T_\infty}\right]^{1/5} = Q = C_D A_h\left[\frac{(T_{en} - T_\infty)gH}{T_\infty}\right]^{1/2} \tag{15}$$

Equations (9) and (15) are two coupled algebraic equations for the unknowns T_{en} and A_h. Eliminating A_h between Eqs. (9) and (15) results in a rather simple expression for T_{en}:

$$T_{en} = T_\infty + \frac{T_w - T_\infty}{1+\dfrac{3.6\pi R^2}{A_\ell}} \tag{16}$$

Substituting T_{en} from Eq. (16) back into Eq. (15) yields the desired expression for A_h:

$$A_h = \frac{1.8\pi\alpha R}{C_D}\left[\frac{T_\infty(1+B)}{(T_w - T_\infty)gH}\right]^{1/2}\left[\frac{gR^3(T_w - T_\infty)B}{\nu\alpha T_\infty(1+B)}\right]^{1/5} \tag{17}$$

where

$$B = \frac{3.6\,\pi R^2}{A_\ell} \tag{18}$$

EXAMPLE CALCULATION

Substituting the parameter values in Table 1 into Eq. (17) yields the minimum value of A_h for improved heat transfer off the bottom of the STSC container:

$$A_h = 2.24 \times 10^{-2}\ m^2 \tag{19}$$

Recall that A_h is the total area of the upper or lower row of holes. The total number N of holes required is

$$N = \frac{4(2A_h)}{\pi D^2} \tag{20}$$

where D is the diameter of the holes. If $D = 5.08 \times 10^{-2}$ m (2.0 in) then

$$N = 22 \text{ holes,} \tag{21}$$

or 11 holes in the bottom circumferential row and 11 holes in the top circumferential row.

The enclosure air temperature corresponding to the minimum hole area for improved lower head heat transfer is, from Eq. (16),

$$T_{en} = 35.5°C \tag{22}$$

The coefficient for natural convection heat transfer off the lower head has already been estimated for $T_{en} \simeq 35°C$ and is given by Eq. (5). The total power $\dot{q}$ removed from the lower head by natural convection of enclosure air is

$$\dot{q} = A_\ell h(T_w - T_{en}) = 35.3\ W \tag{23}$$

The total power generated in the sludge may be as high as 500 W. It may be difficult to justify fabricating a skirt with holes given that the resulting natural convection heat transfer rate off the lower head is such a small fraction of the container power.

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Aihara, T., Yamada, Y., and Endo, S., 1972, "Free Convection Along the Downward-Facing Surface of a Heated Horizontal Plate," Int. J. Heat Mass Transfer 15, pp. 2535-2549.

Churchill, S. W., 1983, in Heat Exchanger Design Handbook, pt. 2, Schlunder, ed., Hemisphere, Washington, D.C.

Fujii, T., Honda, H., and Morioka, I., 1973, "A Theoretical Study of Natural Convection Heat Transfer from Downward-Facing Horizontal Surfaces with Uniform Heat Flux," Int. J. Heat Mass Transfer 16, pp. 611-627.

Singh, S. N. and Birkebak, R. C., 1969, "Laminar Free Convection from a Horizontal Infinite Strip Facing Downwards," Z. Angew. Math. Phys. 20, pp. 454-461.

ME:lak

C.5 FATE Natural Convection Heat Transfer Model Changes and Testing

DATE: March 12, 2010

TO: Bob Apthorpe
Marty Plys

FROM: Sung Jin Lee

SUBJECT: **FATE Natural Convection Heat Transfer Model Changes and Testing**

The attached pages contain a section for FAI/10-93, the new FATE 2.061 Software Change Specification (SCS). The new models tested are for natural convection heat transfer in a narrow gap and on the underside of a hot plate. The applications are for gap heat transfer between a sludge container and shipping cask, and heat transfer from the underside of a sludge container.

7.7 Natural Convection Heat Transfer in a Gap and on Underside of a Hot Plate

Current FATE code considers free convection on a heat conductor surface, heat transfer due to a flow driven by temperature-induced buoyancy from a single surface within quiescent surroundings as shown in Figure 7-10. The surface is assumed to be unbounded by other surfaces. The orientation, IORIHS, and characteristic height, XLHS, of the surface characterize the free convection. This model is extended to consider the presence of a second parallel wall as shown in Figure 7-11. The natural convection heat transfer across the gap is suppressed when the gap narrows and conduction becomes the dominant heat transfer mechanism as shown in Figure 7-12. New inputs for the gap distances to adjacent parallel walls on each side are introduced: XDHSI and XDHSO. These new inputs have default value of 1000, representing free convection on a surface unbounded by other surfaces.

Another improvement made in the heat transfer model considers the heat transfer due to fluid flow within the boundary layer on the underside of a hot plate (or on the top of a cold plate) as shown in Figure 7-13. Current FATE code assumes that natural convection is completely suppressed for this stable configuration and considers only conduction heat transfer from the surface to the bulk fluid.

7.7.1 Natural Convection Heat Transfer Across Gaps

Laminar natural convection heat transfer across high-aspect-ratio-vertical gaps is best estimated with the following correlation that resulted from the theoretical investigations of Gill (1966) and Bejan (1979):

$$\mathrm{Nu} = 0.364\left(\frac{\delta\,\mathrm{Ra}}{\mathrm{H}}\right)^{1/4} \tag{7-15}$$

where δ is the gap dimension, H is the vertical height of the gap, Nu is the Nusselt number defined by

Figure 7-10. Natural Convection Heat Transfer On a Vertical Surface Unbounded by Other Surfaces.

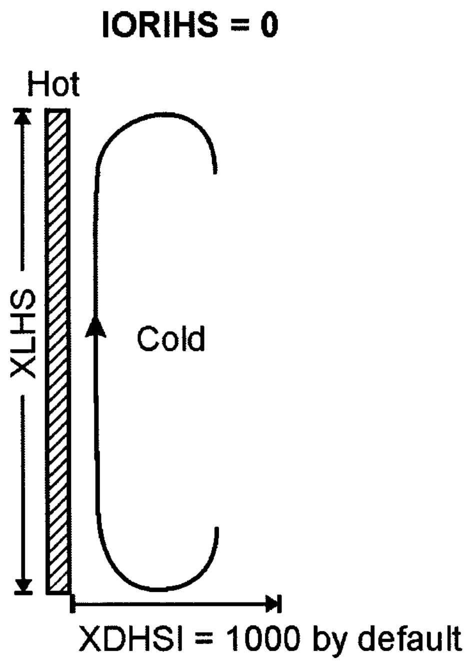


Figure 7-11. Natural Convection Heat Transfer Across a Gap.

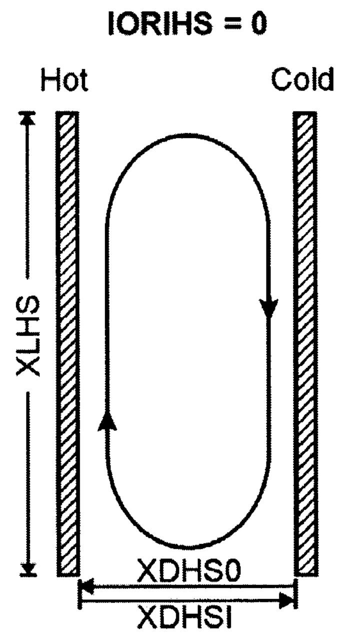


Figure 7-12. Conduction Heat Transfer Across a Narrow Gap

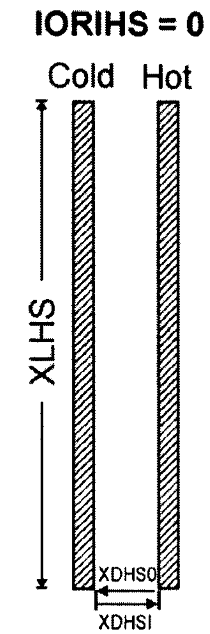
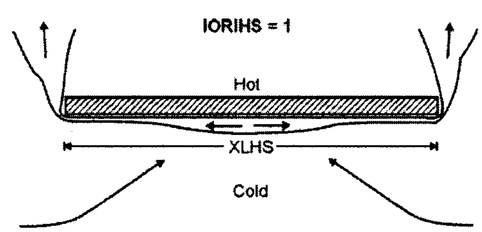


Figure 7-13. Natural Convection on Underside of a Hot Plate



$$Nu = \frac{h\delta}{k} ,$$

and Ra is the Rayleigh number defined by

$$Ra = \frac{g\beta(\Delta T)\delta^3}{\nu\alpha} \tag{7-17}$$

In Eqs. (7-16) and (7-17): h is the heat transfer coefficient for heat flow across the gap due to a temperature difference ΔT across the gap; k, β, ν, α, are, respectively, the thermal conductivity, coefficient of thermal expansion, kinematic viscosity and thermal diffusivity of the fluid that occupies the gap; and g is the gravitational constant.

Equation (7-15) is valid for fluid Rayleigh numbers and gap aspect ratios that satisfy the following inequalities

$$56.9\frac{H}{\delta} \le Ra \le 10^9 \quad ; \quad \frac{H}{\delta} > 1.0 \tag{7-18}$$

When $Ra \le 56.9\ H/\delta$ heat flow occurs by conduction. Above $Ra = 10^9$ the convective flow may become turbulent and the correlation would not apply. A rational formula for the transition from Eq. (7-15) to fully turbulent flow where $Nu \sim Ra^{1/3}$ does not appear to be available in the open literature. However, in most gap heat transfer applications of practical interest $Ra < 10^9$.

7.7.3 Model Implementation - Natural Convection Heat Transfer Across Gaps

From the definition of the heat transfer coefficient, the heat flow $\dot{q}$ (in J s^{-1} m^{-2}) across the gap is

$$\dot{q} = h(\Delta T) = h(T_H - T_C) \tag{7-19}$$

where T_H and T_C are, respectively, the temperatures of the hot and cold surfaces that bound the gap. From Eqs. (7-15), (7-16) and (7-17)

$$\dot{q} = 0.364\,k\left(\frac{g\beta}{\nu\alpha H}\right)^{1/4}(T_H - T_C)^{5/4} \tag{7-20}$$

The structure of the FATE code requires that $\dot{q}$ be expressed in terms of the difference between a boundary temperature and the bulk fluid temperature T_f in the gap. At steady state and sufficiently large Ra boundary layers appear on the vertical surfaces and the core region between the layers may be described by horizontal temperature profile uniformity at T_f. Under these conditions

$$T_H - T_C = 2\,(T_H - T_f) = 2\,(T_f - T_C) \tag{7-21}$$

and Eq. (7-20) becomes

$$\dot{q} = 0.866\,k\left(\frac{g\beta}{\nu\alpha H}\right)^{1/4}(T_H - T_f)^{5/4} \tag{7-22}$$

or

$$\dot{q} = 0.866\,k\left(\frac{g\beta}{\nu\alpha H}\right)^{1/4}(T_f - T_C)^{5/4} \tag{7-23}$$

Under quasi-steady state heatup or cool-down conditions Eqs. (7-22) or (7-23) may be used and in general we may write

$$\mathrm{Nu} = 0.866\left(\frac{\delta \mathrm{Ra}}{H}\right)^{1/4} \tag{7-24}$$

where it is understood that ΔT is the absolute temperature difference between one of the surfaces and the bulk fluid temperature.

At high Ra number fully turbulent flow is assumed:

$$Nu = 0.106\,Ra^{0.3333} \tag{7-25}$$

Since the Ra number is defined in terms of the temperature difference between one surface and the bulk fluid in FATE, the equivalent high Ra number criteria consistent with Eq. (7-18) is Ra > 0.5E9.

At low Ra number convection or in the conduction regime it is probably reasonable to identify the bulk fluid temperature T_f with the arithmetic mean surface temperature $1/2(T_H + T_C)$. This is equivalent to using Eq. (7-21). Thus the heat transfer coefficient for conduction is

$$Nu = 2.0 \tag{7-26}$$

where, again, ΔT is the absolute temperature difference between one of the surfaces and the bulk fluid temperature. With this temperature difference the condition for heat flow via conduction is

$$\mathrm{Ra} \le 28.45 \frac{\mathrm{H}}{\delta} \tag{7-27}$$

7.7.4 Natural Convection on the Underside of a Hot Plate (or on the Top of a Cold Plate)

The air flow within the boundary layer on the underside of a hot plate (or on the top of a cold plate) is laminar and the heat transfer coefficient for rectangular or square plates is well represented by the correlation of Aihara et al. (1972):

$$Nu = 0.5\ Ra^{1/5} \tag{7-28}$$

where Nu and Ra are the Nusselt and Rayleigh numbers based on the half-width R of the plate.

The heat transfer relation for the square plate is about the same as that for the circular plate (Fujii et al., 1973).

7.7.5 Model Implementation - Natural Convection Underside of a Hot Plate

Note that Eq. (7-27) is based on the half-width R of the plate. Since the FATE input for the characteristic length of a plate represents the total width L of the plate, Eq. (7-28) needs to be rewritten in terms of 'L'. The heat transfer coefficient underside of a hot plate is given by

$$h_c = Nu\ k / R \tag{7-29}$$

Substituting Eq. (7-28),

$$h_c = 0.5\ Ra^{1/5}\ k / R \qquad (7\text{-}30)$$

Since the Rayleigh number based on the half-width R of the plate is 1/8 of the Rayleigh number based on the full width L of the plate, Eq. (7-30) can be rewritten as

$$h_c = 0.5\ (1/8)^{1/5}\ Ra_L^{\ 5}\ k / (L/2) \qquad (7\text{-}31)$$

where Ra_L is the Rayleigh number based on the full width L of the plate.

Or,

$$h_c = 0.5 \times 4^{1/5}\ Ra_L^{\ 5}\ k / L \qquad (7\text{-}32)$$

Hence, the heat transfer correlation implemented in FATE code for natural convection on the underside a hot plate, or on the top of a cold plate, is

$$Nu_L = 0.66\ Ra_L^{\ 1/5} \qquad (7\text{-}33)$$

where Nu_L and Ra_L are Nusselt and Rayleigh numbers based on the full-width L of the plate.

7.7.6 New Inputs

New inputs for the gap distances to adjacent parallel walls on each side are introduced: XDHSI and XDHSO. These new inputs have default value of 1000, representing free convection on a surface unbounded by other surfaces.

7.7.7 Test Requirements

The natural convection in a narrow gap model should be tested to demonstrate that it can reproduce the expected heat transfer coefficient for an unbounded surface and between two surfaces separated by various size gaps. The natural convection on a downward facing hot surface should be tested to demonstrate that it can reproduce the expected heat transfer coefficient underside of a hot plate.

7.7.8 Test Description

The first test consists of a 10 m tall, 1 m wide, 0.01 m thick vertical steel plate with one surface fixed at 60 °C and the other surface facing the atmosphere of a large room at 25 °C. The emissivity of the surface is set to 1.E-5 to disable the radiative heat transfer. The thermal diffusivity, kinematic viscosity and thermal conductivity of the 25 °C air are, respectively, ν = 1.572E-5 $m^2\ s^{-1}$, α = 2.176E-5 $m^2\ s^{-1}$ and k = 0.02548 W $m^{-1}\ K^{-1}$. The height of the wall is L = 10 m and the one-side surface area of the wall is A = 10 m^2. The Rayleigh number is

$$Ra = \frac{g\left|T_w - T_g\right| L^3}{\nu\,\alpha\,T_g} = 3.367E12 \tag{7-34}$$

and the Nusselt number for turbulent natural convection on the vertical surface is

$$Nu = 0.106\,Ra^{0.3333} = 1587 \tag{7-35}$$

From the definition of Nu the heat transfer coefficient for natural convection on the vertical surface is

$$h = \frac{k\,Nu}{L} = 4.044\,W\,m^{-2}\,K^{-1} \tag{7-36}$$

Finally, the heat transfer rate from the hot surface to the air in the room is given by

$$Q = h\,A\left(T_w - T_g\right) = 1415\,W \tag{7-37}$$

The second test consists of two vertical parallel plates, each 10 m tall, 1 m wide, and 0.01 m thick. The inner surface of the first plate is facing the inner surface of the second plate. The outer surface of the first plate is fixed at 50 °C and the outer surface of the second plate is fixed at 40 °C. Initially the two plates are 20 m apart. The gap distance is reduced to 8 m at 100 seconds, to 0.1 m at 200 seconds, and 0.01 m at 300 seconds. Again, the emissivities of all surfaces are set to 1.E-5 to disable the radiative heat transfer. The thermal diffusivity, kinematic viscosity and thermal conductivity of the 45 °C air are, respectively, ν = 1.653E-5 $m^2\ s^{-1}$, α = 2.294E-5 $m^2\ s^{-1}$ and k = 0.02694 W $m^{-1}\ K^{-1}$. The height of the wall is L = 10 m and the one-side surface area of the wall is A = 10 m^2. Initially, when the gap distance exceeds the height of the plates, the surfaces are each considered unbounded. FATE computes heat transfer rate from the first plate to the bulk gas in the gap and from the gas to the second plate. Since the gap will take up the average temperature between the two plates, 45 °C, the corresponding Rayleigh number is

$$Ra = \frac{g\left|T_w - T_g\right| L^3}{\nu\,\alpha\,T_g} = 4.066E11 \tag{7-38}$$

and the Nusselt number for turbulent natural convection on the vertical surface is

$$Nu = 0.106\,Ra^{0.3333} = 784.6 \tag{7-39}$$

From the definition of Nu the heat transfer coefficient for natural convection on the vertical surface is

$$h = \frac{k\,Nu}{L} = 2.114\,W\,m^{-2}\,K^{-1} \tag{7-40}$$

Finally, the heat transfer rate from the hot surface to the air in the room is given by

$$Q = h\,A\left(T_w - T_g\right) = 106\,W \tag{7-41}$$

When the two plates are brought closer at 100 seconds, the new gap distance, 8 m, decreases below the height of the plates, 10 m. With δ = 8 m and T_g = 45 °C, the Rayleigh number is

$$Ra = \frac{g\left|T_H - T_g\right| \delta^3}{\nu\,\alpha\,T_g} = 2.082E11 \tag{7-42}$$

It is greater than the critical Ra number for fully turbulent flow, 0.5E9, and the corresponding heat transfer rate is given by Eq. (7-25),

$$Nu = 0.106\,Ra^{0.3333} = 627.7 \tag{7-43}$$

From the definition of Nu the heat transfer coefficient for natural convection in the gap is

$$h = \frac{k\,Nu}{\delta} = 2.114\,W\,m^{-2}\,K^{-1} \tag{7-44}$$

Finally, the heat transfer rate across the gap is given by

$$Q = h\,A\left(T_w - T_g\right) = 106\,W \tag{7-45}$$

When the gap distance decreases to 0.1 m at 200 seconds, the Ra number in Eq. (7-42) decreases to 4.07E5, below the critical value for fully turbulent flow, and the natural convection heat transfer rate across the gap is given by Eq. (7-20). With $\beta = 1/T_g = 3.143E\text{-}3\ K^{-1}$, H = 10 m, and $(T_H - T_C)$ = 10 K, Eq. (7-20) gives

$$\dot{q} = 0.364\,k\left(\frac{g\beta}{\nu\alpha H}\right)^{1/4}(T_H - T_C)^{5/4} = 9.312\ W\ m^{-2} \tag{7-46}$$

The heat transfer rate from the hot plate to the cold plate across the gap is

$$Q = A\,\dot{q} = 93.12\,W \tag{7-47}$$

When the gap distance decreases further to 0.01 m at 300 seconds, the Ra number in Eq. (7-42) decreases to 4.07E2. It is less than the critical value for heat flow via conduction in Eq. (7-27), $28.45\,\frac{H}{\delta} = 2.85E4$. The conduction heat transfer is given by $A\,k\,\frac{\left(T_H - T_C\right)}{\delta} = 269\,W$.

The third test consists of a 2 m by 2 m square plate, with the top surface fixed at 100 °C and the bottom surface facing the atmosphere of a large room at 25 °C. The half-width of the plate R = 1 m. The Rayleigh number in Eq. (7-27) is then

$$Ra = \frac{g\left|T_w - T_g\right|R^3}{\nu\,\alpha\,T_g} = 7.214E9 \tag{7-48}$$

and the Nusselt number from Eq. (7-27) is

$$Nu = 0.5\ Ra^{1/5} = 46.8 \tag{7-49}$$

From the definition of Nu the heat transfer coefficient for natural convection on underside of the hot surface is

$$h = \frac{k\ Nu}{R} = 1.19\ W\ m^{-2}\ K^{-1} \tag{7-50}$$

Finally, the heat transfer rate from the hot surface to the air in the room is given by

$$Q = h\ A\left(T_w - T_g\right) = 357\ W \tag{7-51}$$

The test cases are constructed in the FATE input file HGAP.DAT.

7.7.9 Test Results

Test results are shown in Figure 7-14. The upper left figure shows the vertical wall, horizontal wall, and the room temperatures for the first and third test cases. They are, respectively, 60 °C, 100 °C, and 25 °C. The lower left figure shows the heat transfer rates on the vertical wall and on the underside of the horizontal wall. The code predicted values of 1413 W and 358 W agree with the expected heat transfer rates of 1415 W and 357 W.

The upper right figure shows the temperature of the two parallel plates and the air gap. Two plates are kept at constant temperatures of 50 °C and 40 °C. The air in the gap heats up gradually and assumes the average temperature between the two plates, 45 °C. Although gap heat transfer correlations are normally written in terms of the heat transfer rate from one surface to another, in FATE heat transfer occurs in two steps, from the hot surface to the bulk gas in the gap and from the gas to the cold surface. Hence, the test should demonstrate that the two-stage heat transfer calculation in FATE reproduces the surface-to-surface heat transfer correlation. The lower left figure shows the heat transfer rates on the two plates as the gap distance is changed every 100 second: 20 m at 0 seconds, 8 m at 100 seconds, 0.1 m at 200 seconds, and 0.01 m at 300 seconds.

Different heat transfer correlation is exercised at each gap distance. Initially, the gap is sufficiently large for the surfaces to be treated as unbounded surfaces. The FATE calculated heat transfer rate of 106 W is consistent with the expected value of 106 W. After 100 seconds, the fully turbulent natural convection prevails in the gap. The FATE calculated heat transfer rate of 105.5 W agrees with the expected value of 106 W. After 200 seconds, when the gap distance is decreased to 0.1 m, laminar natural convection prevails in the gap. The FATE calculated heat transfer rate of 93.03 W agrees with the expected value of 93.12 W. Lastly, after 300 seconds, when the gap distance is reduced to 0.01 m, conduction heat transfer prevails in the gap. The FATE calculated heat transfer rate of 269 W agrees with the expected value of 269 W. In conclusion, the test demonstrates all the behavior expected from the test requirements and test description.

7.7.10 Reference

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Figure 7-14. Test Results for Natural Convection Heat Transfer in a Gap and on Underside of a Hot Plate.